Winners of 2007 BioScapes Photo Contest (*page 78*)

SCIENTIFIC AMERICAN

Inventor of
MULTIPLE UNIVERSES
page 98

December 2007 www.SciAm.com

ARE WE LIVING WITH
ALIEN CELLS?

Did life on Earth arise more than once?
Strange forms may still survive

Semantic Web
How the Internet
Is Getting Smarter

Carbon Markets
Making Them Work
to Save the Climate

Gamma Rays
New Space Telescope
Could Change Physics

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SCIENTIFIC AMERICAN December 2007 ■ Volume 297 Number 6

62 BIOLOGY

Are Aliens among Us?

By Paul Davies

All life on Earth is generally understood to have descended from a common ancestor. But if cells evolved independently more than once, some microbes radically different from all known organisms might still survive in extreme environments of our planet. The search is on for evidence of these strangers.

Image by Jean-Francois Podevin

ASTRONOMY

54 **Window on the Extreme Universe**

By William B. Atwood, Peter F. Michelson and Steven Ritz

The GLAST satellite is about to open up an unexplored region of the electromagnetic spectrum, where dark matter and other mysteries might be seen.

ENVIRONMENT

70 **Making Carbon Markets Work**

By David G. Victor and Danny Cullenward

Limiting climate change without damaging the world economy depends on stronger and smarter market signals to regulate carbon dioxide.

GALLERY

78 **Radiant Information**

By Emily Harrison

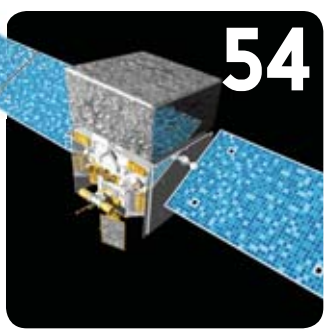
State-of-the-art light microscopy from the Olympus BioScapes competition illuminates life exquisitely.

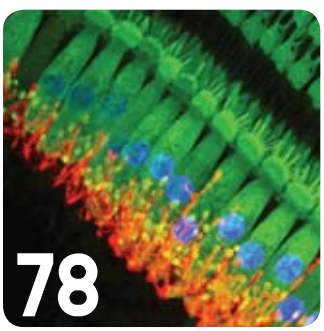
GENETICS

84 **Diet Advice from DNA?**

By Laura Hercher

Are personalized diets based on genetic tests cutting-edge science or high-tech horoscopes?





ON THE COVER

One can only guess how different cells that evolved independently of conventional life might look or act. Artist Adam Questell has imagined an alien cell that carries its genetic material in twin nuclei.

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MORE FEATURES

INFORMATION TECHNOLOGY

90 **The Semantic Web in Action**

By Lee Feigenbaum, Ivan Herman, Tonya Hongsermeier, Eric Neumann and Susie Stephens

Networks that handle data more intelligently are already here.

HISTORY OF PHYSICS

98 **The Many Worlds of Hugh Everett**

By Peter Byrne

Whatever became of the creator of the now celebrated quantum theory of multiple universes?

CROSSWORD

106 **In Boxes**

By Patrick Merrell

Challenge your knowledge of science and the past year's issues of this magazine.

SCI AM

Cash for Carbon Dioxide

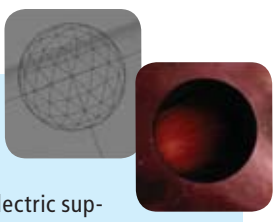
An expanded version of the article on carbon markets by David G. Victor and Danny Cullenward can be found at **www.SciAm.com/ontheweb**

GO TO SCIAM.COM

How Artists Portray Exoplanets They've Never Seen

Planets outside our solar system are too faint to be distinguished from the stars they orbit, yet popular news accounts overflow with bold, almost photorealistic images of distant worlds. To find out how it is done, visit us at **www.SciAm.com/ontheweb**

GREG BACON STScI, NASA



COURTESY OF TIM PYLE (*planet mock-ups*)

In Focus

Sunny Outlook: Can Sunshine Provide All U.S. Electricity?

Large amounts of solar-thermal electric supply may become a reality if steam storage technology works—and new transmission infrastructure is built.

News

Don't Forget: Drink a Beer—or Two—Daily!

Study in rats suggests long-term, moderate consumption of alcohol improves recall of both visual and emotional stimuli.

Podcast

Plant Passion Truly Hot

Male cycad plants use heat to attract and repel thrips, whose comings and goings fertilize female cycads.

Blog

God Is in Your Mind

Not to put too fine a point on it, but so is everything else.

Strange but True

Less Sleep Means More Dreams

Missing sleep tonight may just boost your dreams tomorrow night.

WANT MORE? Everything described here, plus Web-exclusive supplements to the articles in this issue, can be found at **www.SciAm.com/ontheweb**

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DEPARTMENTS

12 **From the Editor**

14 **Letters**

20 **50, 100 & 150 Years Ago**

22 **Updates**

24 **NEWS SCAN**

- AIDS: Can immunosuppressants fight off HIV?
- Decline in hormonal response to pheromones?
- Testing for drugs in municipal sewage.
- Night-vision goggles light up the night.
- Shock-wave engine pulses to save fuel.
- More virulent space bacteria.
- Evolution in a petri dish.
- Data Points: A smaller ozone hole?
- The 2007 Nobel Prizes.

OPINION

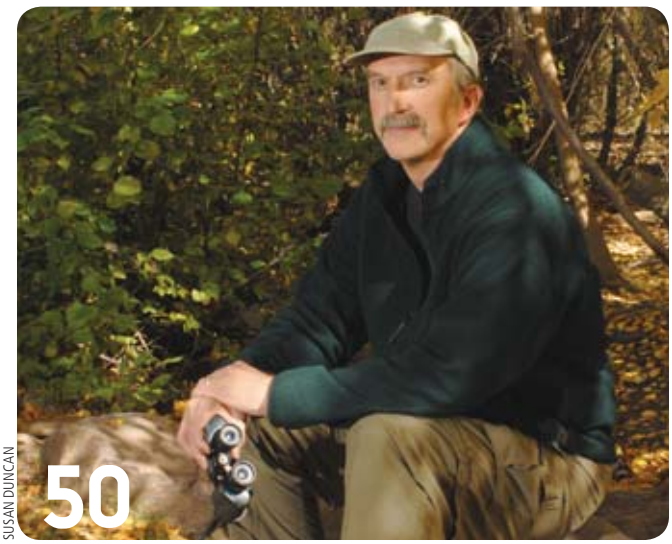
40 **SciAm Perspectives**
Do more than talk about the climate.

42 **Sustainable Developments**
By Jeffrey D. Sachs
Small steps to big climate progress.

46 **Forum**
By Rob Dunn
Human changes to the environment are accelerating evolution.

48 **Skeptic**
By Michael Shermer
How science really works.

49 **Anti Gravity**
By Steve Mirsky
Apples and squeaky cheese.



SUSAN DUNCAN

Negotiating Climate
Can the new Bali talks on controlling CO_2 emissions do more than Kyoto did? Join the debate at **www.SciAm.com/ontheweb**

50 **Insights**
Sasquatch is just a legend, right? Maybe not, anthropologist Jeffrey Meldrum argues.

108 **Working Knowledge**
Adaptive cruise control.

112 **Reviews**
Books to give, books to get.

114 **Ask the Experts**
How do short-term memories become long-term memories?

116 **Fact or Fiction?**
Is chocolate poisonous to dogs?

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SCIENTIFIC AMERICAN Digital

Worlds Apart

Physics and biology both reveal overlooked universes alongside our own

Storytellers have traditionally found it useful to isolate the strange lands, people and events of their wildest fictions far from the precincts of their audiences. L. Frank Baum put Oz on the other side of a whirlwind; George Lucas set Tatooine a long time ago in a galaxy far, far away; C. S. Lewis had Narnia; and Homer's Odysseus navigated uncharted isles of the ancient Mediterranean. Enough separation in space and time can make almost any circumstance seem more plausible. The corresponding trick of good storytelling is then to make what seems impossibly odd and distant also still feel both real and relevant to the here and now.

Physicist Hugh Everett managed to pull off a similar trick for quantum mechanics by proposing a many-worlds interpretation of it half a century ago. His novel idea was that we occupied only one member of an infinitely branching set of "what if?" universes that were each as authentic as ours but forever isolated from it in a parallel reality. As the story by Peter Byrne starting on page 98 explains, physicists were slow to take that interpretation seriously, much to Everett's disappointment, and of course it remains debatable, but today parallel worlds are useful devices for physicists and fabulists alike.

SEPARATE, unsuspected worlds

Science also holds plenty of exotic worlds that are not exactly parallel to our own. Rather they intersect or overlap ours to a degree but are generally outside direct human experience. Beyond the frequencies of sound that we can hear and of light that we can see, very different realities can present themselves.

The universe of the gamma-ray spectrum, for example, is utterly invisible to us. But it is painted in the colors of the most energetic events in the cosmos: massive stellar explosions, black hole collisions and similar catastrophes. When NASA launches its new Gamma-ray Large Area Space Telescope next spring, its scientists hope to unveil the enigmas of the dark matter that holds galaxies together, and they may even discover phenomena that force revisions in the fundamental models of particle physics. "Window on the Extreme Universe," by William B. Atwood, Peter F. Michelson and Steven Ritz, beginning on page 54, explains in more detail.

Biology, too, has hidden worlds. Some of them are ordinarily kept from us by a gulf in scale: unaided human eyes cannot resolve the beauties of cellular structures below a certain magnitude of size. Modern lenses can, however. This year we are pleased to present a portfolio of some of the winning entries in the 2007 Olympus BioScapes Digital Imaging Competition (turn to page 78), which highlights exceptional pictures of biological specimens captured through light microphotography. Such images are rich reminders of the extraordinary things that lurk around and within us.

Some of those lurkers may be stranger than others. In "Are Aliens among Us?" (page 62), Paul Davies ponders whether life on Earth arose more than once and whether cells surviving from those other origins might be as biochemically distinct from more familiar organisms as anything from a different planet could be. Such alien cells would have followed their own evolutionary journey for billions of years in parallel with those of our ancestry. Even if aliens do not exactly walk among us, they may coexist with us, unseen. ■

JOHN RENNIE
editor in chief

FLYNN LARSEN (*Rennie*); ALFRED T. KAMAJIAN (*multiverse*)

Among Our Contributors

PETER BYRNE
is an investigative journalist and science writer based in northern California. He is currently at work on a book-length biography of theoretical physicist Hugh Everett.

PAUL DAVIES
is a physicist, astrobiologist and one of today's most prolific and highly honored science writers. He is currently also research director of Beyond, a research center at Arizona State University.

LAURA HERCHER
of Sarah Lawrence College has most recently been focusing on the legal and social implications of genetic testing for risks of complex ailments that involve many genes, such as schizophrenia.

PATRICK MERRELL
is a professional puzzlemaker who has contributed end-of-year crosswords to *Scientific American* for the past three years. He is also the author of many books, including his latest, *Coffee Time*.

DAVID G. VICTOR
serves as director of the Program on Energy and Sustainable Development at Stanford University, where his co-author Danny Cullenward also works as a research associate.

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LETTERS

editors@SciAm.com

Global Warming ▪ Race-Specific Drugs ▪ Eye Tics

AUGUST 2007

"Given the magnitude of benefit of BiDil, it is a travesty that polarizing race-based arguments have paralyzed implementation of the best care for a disadvantaged patient population."

—*Clyde W. Yancy* ASSOCIATION OF BLACK CARDIOLOGISTS

Atmosphere of Uncertainty?

To support the conclusion of the Intergovernmental Panel on Climate Change (IPCC) that current warming is anthropogenic, William Collins, Robert Colman, James Haywood, Martin R. Manning and Philip Mote assert in "The Physical Science behind Climate Change" that the mismatch between surface and tropospheric warming rates has now been resolved. This claim is not supported by actual observations. According to the April 2006 Climate Change Science Program (CCSP) report, considerable disparity exists between the observed warming-rate patterns and those calculated by greenhouse models. Although the models predict that temperature trends will increase with altitude by 200 to 300 percent, the data from both weather balloons and satellites show the opposite. This result does not deny the existence of a greenhouse effect from the considerable increase in anthropogenic greenhouse gases. But it does suggest that present models greatly overestimate the effect's magnitude and significance.

S. Fred Singer
University of Virginia

THE AUTHORS REPLY: *Contrary to Singer's assertions, the IPCC and CCSP are in very close agreement regarding tropospheric warming trends. The CCSP states: "For globally averaged temperatures, model-predicted trends in tropospheric lapse rates [vertical gradients in atmospheric temperature] are consistent with observed results." The recent confirmation of consistency among global models and observations represents a major advance in climate change science. As Singer notes, the CCSP reports less consistency among the long-term observational and model-predicted trends in tropospheric lapse rates for tropical regions. He has, however, omitted the April 2006 report's conclusions on this subject. The explanation favored by the CCSP is that these discrepancies arise from "significant nonclimatic influences remaining within some or all of the observational data sets" rather than "errors common to all models."*

Race and Remedy

"Race in a Bottle," by Jonathan Kahn, suggests that introducing BiDil as a therapy for heart failure in African-Americans was a harmful, commercially motivated decision. This perspective is not shared by all.

Heart failure is a serious illness. It is clear that *all* persons afflicted should receive the best available evidence-based therapies to optimize the quality and longevity of their life. BiDil has been proved to benefit patients with heart failure. The science supporting its use is sound and incontrovertible. The point of controversy is the drug's unique indication in African-Americans. Heart failure in African-Americans is problematic: the condition is more likely to occur, occurs at an earlier age, is clearly more severe, leads to more hospitalizations and causes more death in those

SCI AM

Read more about "Race in a Bottle," including an expanded letter from Yancy and replies from Kahn at **www.SciAm.com/ontheweb**

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*Assumes spiral replacement after 1,000 cork pulls

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younger than 65 years. It is entirely plausible that BiDil will work in others, but so far race is the only "marker" of drug responsiveness. More research, especially gene-based research, is under way. But given the magnitude of benefit of BiDil, and the gravity of heart failure in African-Americans, it is a travesty that polarizing race-based arguments have paralyzed implementation of the best care for a disadvantaged patient population. These debates need to cease so that effective therapy may proceed.

Clyde W. Yancy
Association of Black Cardiologists

Bobbing and Perceiving

In "Windows on the Mind," Susana Martinez-Conde and Stephen L. Macknik write about tiny eye tics known as microsaccades that enable us to see more clearly. A long time ago I was intrigued by a report that stated that the familiar bob of pigeons' heads is integral to their vision. Do pigeons use this head bob as an evolutionary equivalent to our microsaccades?

Bruce Resch
East Meadow, N.Y.

YOUR EYE needs to move to focus on the important things in life.

THE AUTHORS REPLY: *This is an interesting question that we had not previously considered. According to physiologist Roger H. S. Carpenter, some striking differences exist between fixational eye movements of birds and those of primates. In the pigeon and the owl, there are short bursts of miniature eye movements, with frequencies of 20 to 30 hertz and amplitudes equal to or greater than 2 degrees of visual angle. The perceptual effects of these oscillations are unknown, but they may perform a similar task to that of fixational eye movements in primates, including humans. Pigeons also use head motions to stabilize the retinal image during locomotion. (They can therefore fixate their gaze while they walk!) The result is the slightly comical gait of birds such as chickens and ducks, in which the body walks on while the head is temporarily left behind, to be jerked forward again at the next step (sometimes called "nystagmus" of the head). It is not clear whether pigeons' head bobbing improves their vision per se, but they do use a combination of head and fixational eye movements to control visual fixation.*

Thirsty Machine

In "Data Center in a Box," M. Mitchell Waldrop competently describes how servers operating within a shipping container can be more efficiently cooled. But I find the accompanying photograph of such a container in an arid province, placed for "humanitarian aid," to be incongruous and of poor taste. The issue is how to cool the 60 gallons of hot water leaving and returning to the container every minute. What many do not realize is that removing heat from water with an efficient industrial chiller can also consume water, exactly what indigenous peoples in such arid areas do not have!

Robert Garner
via e-mail

ERRATA "The Shark's Electric Sense," by R. Douglas Fields, states that a shark can sense one millionth of a volt per centimeter of seawater. The figure should have been given as 10 billionths of a volt per centimeter—equivalent to sensing a 1.5-volt battery across 1,500 kilometers of seawater.

In the box "How BiDil Treats Heart Failure," on page 44 of "Race in a Bottle," by Jonathan Kahn, nitric oxide is incorrectly labeled as NO_2 rather than NO.

"How does catnip work its magic on cats?" by Ramona Turner [Ask the Experts], refers to the amygdala as residing in the midbrain. The correct location is the forebrain.

Letters to the Editor

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Letters may be edited for length and clarity. We regret that we cannot answer all correspondence.

BRIAN MARANAN PINEDA

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Space Race ▪ Cost of Coal ▪ An Uncivil Club

Compiled by Daniel C. Schlenoff

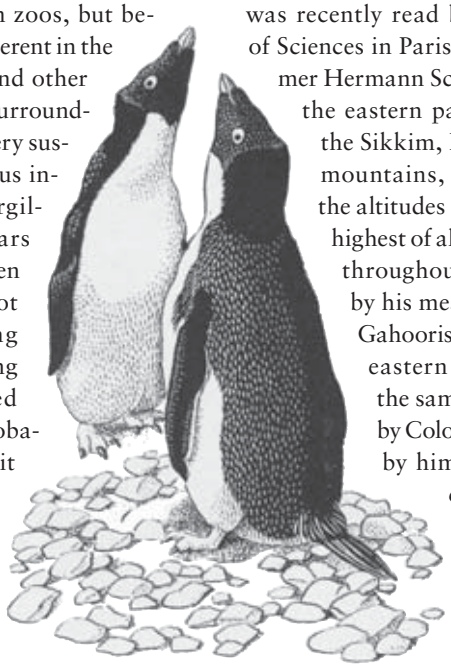
DECEMBER 1957

SPUTNIK 2—"With the launching by the U.S.S.R. of its second artificial satellite, weighing half a ton and carrying the first living being into space—a little dog named Laika—scientists the world over were ready to accept the age of space travel as already born. A rocket shot to the moon seemed imminent. An official statement, issued through the Soviet news agency Tass, said that 'the increase in the satellite's size to provide for a large number of measuring and telemetering instruments, and even for an animal passenger, necessitated the development of improved new instruments and sources of power.'"

[UPDATE: Not until 2002 was it revealed that Laika had died within seven hours of launch, probably from stress and heat.]

EXHIBIT OF THE PENGUINS—"Penguins are a popular exhibit in zoos, but besides the hazards inherent in the change of climate and other alterations of their surroundings, penguins are very susceptible to the fungus infection called aspergillosis. In recent years several zoos have been able to keep, but not breed, cold-loving penguins by building special refrigerated rooms for them. Probably the best exhibit of penguins behind glass in the world today is the one in the Bronx Zoo. There penguins of the emperor, king, chinstrap and other species disport themselves in a cooled tank to the delight of thousands of visitors.

—William J. L. Sladen"



ADÉLIE PENGUINS, 1957

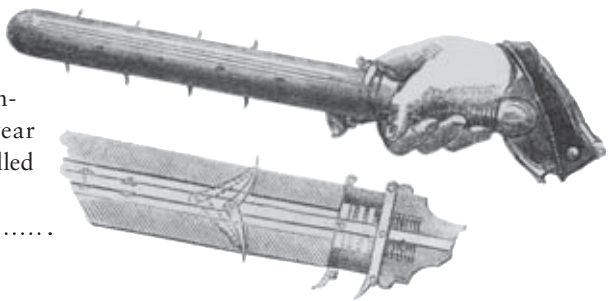
DECEMBER 1907

COAL MINES—"Secretary Garfield of the Interior Department announces that the number of mining accidents, caused directly or indirectly by mine explosions, has been steadily increasing. Their increase is attributed in part to the lack of proper and enforcible mine regulations; to ignorance of the explosives and the proper conditions of their use in the presence of gas and dust. Also, not only is the number of miners increasing, but the coal is being taken from greater depths or farther from the entrance, in locations where ventilation becomes increasingly difficult. During the year 1906, no less than 2,061 men were killed outright in the mines."

DECEMBER 1857

TOP OF THE WORLD—"An interesting paper was recently read before the Academy of Sciences in Paris. In 1855 in the summer Hermann Schlagintweit explored the eastern part of the Himalaya, the Sikkim, Bhootan, and Kossia mountains, where he measured the altitudes of several peaks. The highest of all the summits known throughout the world appears by his measurements to be the Gahoorishanke, situated in the eastern portion of Nepaul, the same announced as such by Colonel Waugh, but called by him Mount Everest, because he had been unable to ascertain its real name in the plains of Hindostan. This peak is more than 29,000 feet in height."

SPIKES FOR PEACE—"This club, which has been refused a patent by the Commissioner of Patents, is especially intended for the protection of policemen and constables. It is made hollow, and when it is grasped by any one trying to wrest it from the policeman, the latter can, by pulling the trigger, force out a number of small spikes as seen in Fig. 2. These spikes, entering a short distance into the attacker's hand, force him to let go. It is almost unanimously admitted that these clubs ought to be at once adopted by the police of every city in the world."



SPIKED TRUNCHEON (patent rejected), 1857

[NOTE: The Patent Commissioner's decision, and *Scientific American*'s reply, can be seen at **www.SciAm.com/ontheweb**]

SPECTER OF MALARIA—"A new expedition has been fitted out in England for the purpose of further exploring the celebrated river Niger, which is described by the Moors under the name of *Nel el Abeed*, or the 'river of slaves,' and called by the negroes, *Joliba*, or the 'great waters.' The chief obstacle to the advance of Europeans into the interior of Africa has hitherto been the terrible climate. This has proved most deadly to the white race, and has been the great barrier to travelers and to missionaries. During an expedition in 1855, an experienced physician gave quinine to every man on board, every day. The result was that the expedition did not lose a man! The scourge of Africa was completely disarmed. Thus fortified against the climate, the present expedition will probably be able to prosecute its voyage in safety."

SCIENTIFIC AMERICAN, VOL. 197, NO. 6, DECEMBER 1957 (penguins); VOL. XIII, NO. 13, DECEMBER 5, 1857 (club)

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Absent Southpaws ▪ Alzheimer's as Diabetes? ▪ Turtle Clues ▪ Missing Mass

Edited by Philip Yam

Left Behind

Ned Flanders's Leftorium would not have stood a chance in Victorian England. Left-handers made up only about 3 percent of the population there, as compared with about 11 percent today globally [see "Taking Sides"; SciAm, April 2006, and "Left Out"; SciAm Mind, December 2005]. Researchers came to this conclusion after watching documentary films about northern England from 1897 to 1913, some of which showed people waving (a better indicator of handedness than writing). The dearth did not result from increased mortality—most of the southpaw wavers were older folks. The investigators speculate that social stigmatization may have led to their decline in the 19th century, as the industrial revolution produced machines suited for right-handers rather than left-handers. That disparity made lefties stand out, and they were presumably shunned as marriage partners. The study appears in the September 18 *Current Biology*.

Insulin-Resistant Memory

Alzheimer's disease may be a novel variety of diabetes. Researchers at Northwestern University experimented with a form of amyloid beta–derived diffusible ligands (ADDLs), which are small, soluble proteins that can travel around the body like hormones. Like amyloid beta and tau proteins, these molecules are often found in the brains of Alzheimer's patients [see "Shutting Down Alzheimer's"; SciAm, May 2006, and "Downsized Target"; SciAm, May 2004].

Applying ADDLs to mature cultures of hippocampal neurons, the researchers found that the proteins specifically bind to the tips of nerve endings at synapses. This precise attachment quickly shut down the replenishment of insulin receptors by inhibiting their transport from the cell body, where they are manufactured. The resulting resistance to insulin, a hormone that helps cells regulate the metabolism of sugar, destroys the capability of memory neurons to communicate properly.

Based on such evidence, investigators have begun to view Alzheimer's disease less as nerve cell death and more like synapse failure. According to team leader William Klein, who published the work August 24 online in the *FASEB Journal*, this perspective could clarify why some people have an abundant number of plaques yet remain cognitively healthy and why elderly type 2 diabetics usually have memory problems.

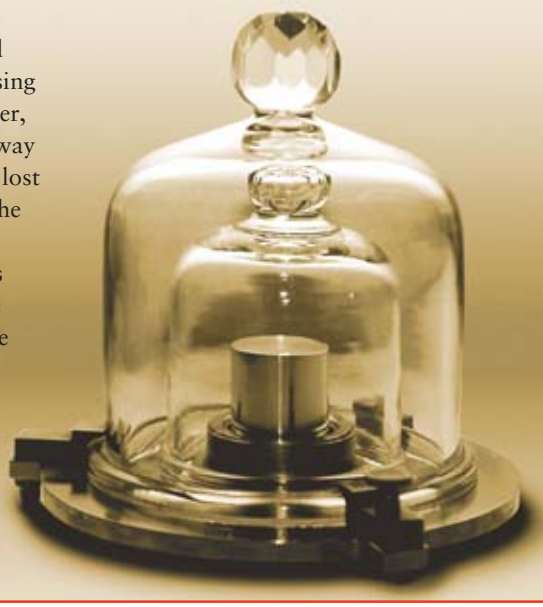
—Peter Sergo

Meat-Loving Hatchlings

The time after hatchling sea turtles scamper down a beach and before they return years later as egg-laying adults has largely been a natural history mystery [see, for instance, "How Sea Turtles Navigate"; SciAm, January 1992]. Biologists at the University of Florida report key insights into these "lost years" online September 18 in *Biology Letters*. The team examined nitrogen isotopes in shell samples; this so-called stable isotope analysis reveals where an animal resides in the food chain—a skew toward heavy isotopes from light isotopes suggests a meatier diet. From their analyses, the researchers conclude that green sea turtles are initially carnivorous, preying on jellyfish and other creatures; three to five years later the turtles switch to sea grass and move closer to shore.

Killing the Kilogram

In September news reports proclaimed that the kilogram was mysteriously losing mass. Specifically, the reference cylinder, made 118 years ago and kept locked away under glass in France, appears to have lost 50 micrograms when compared with the average of dozens of copies. Physicists have long recognized this kind of mass drift, however, which is why they have been seeking natural definitions for the kilogram [see "Weighty Matters"; SciAm, December 2006]. One possibility for a new definition would be the number of silicon atoms in a kilogram of pure silicon; another would rely on electrical power and quantum effects.



COURTESY OF THE NATIONAL INSTITUTE OF METROLOGICAL RESEARCH, TORINO, ITALY (*kilogram*); ANDY ROUSE *Corbis* (*sea turtle*); THOMAS NORTHCUT *Getty Images* (*woman waving*)

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HIV/AIDS

T Cell Turnoff

Can suppressing the immune system treat HIV infection? BY BIANCA NOGRADY

HIV is devastating because it attacks and destroys the body's defense system against pathogens, leaving patients fatally exposed. So what would possess scientists to treat HIV-positive patients with drugs that suppress the immune system?

Such therapy may in fact offer a new approach in the battle against AIDS. An unexpected feature of HIV infection is that in the first few weeks after invasion, the virus hijacks the immune system and sends it into overdrive. Most significantly, the activated T cells—the soldiers that fight germs—not only produce large amounts of cytokines (chemical messengers that help to coordinate a counterattack) but also enter the cell cycle, a process that normally leads to cell division and proliferation. In HIV infection, however, a T cell subtype called the central memory CD4+ T cell appears to enter the cell cycle and undergo apoptosis—cellular suicide—in vast numbers. The activated CD4+ T cell population also helps the virus replicate.

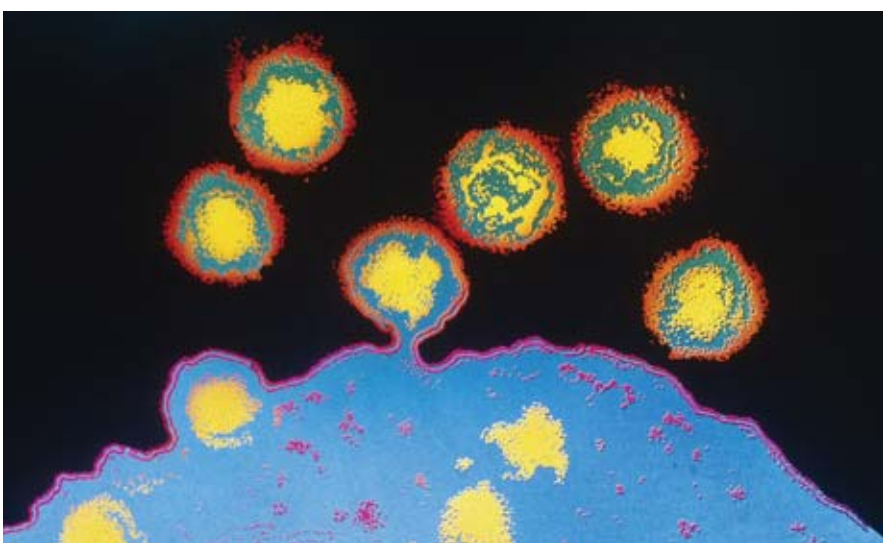
Scientists are not exactly sure how HIV causes the CD4+ T cell population to activate and crash. They do know that the decline is characteristic of HIV infection and use it to make prognoses. They also know that if immune activation is absent, the outlook is very different.

Nowhere is this clearer than in the laboratory with monkeys. The sooty mangabey, found in West Africa, has somehow adapted to the simian immunodeficiency virus—the nonhuman version of HIV—so that even with a high viral load, it rarely gets sick. In contrast, the Asian rhesus macaque will commonly develop a syndrome resembling AIDS. The difference between these two primates is that the sooty mangabey experiences only low levels of immune activation, which presumably limits the T cell population crash and viral replication. In contrast, the rhesus macaque's immune system, like that of humans, is highly activated in the early stages of infection.

This correlation led researchers to wonder what might happen if the human immune system behaved more like the mangabey's when confronted by the virus. Experiments have already established that blocking viral replication with antiretroviral medication attenuates immune activation and boosts the number of CD4+ T cells. The next step would be immunosuppressive therapy, which could slow down viral replication by limiting the T cell activation and prevent the CD4+ T cells from committing suicide. "Maybe if we gave antiviral medications and blocked the downstream pathways that are driving T cell turnover, we might be able to enhance CD4+ T cell restoration and T cell function," says Michael Lederman, director of the Center for AIDS Research at Case Western Reserve University.

Several teams around the world have been investigating this unusual approach, with mixed results. Lederman and his colleagues conducted trials in 2001 and 2003 of the corticosteroid prednisone in conjunction with antiretroviral therapy. The therapy succeeded in blocking immune activation but failed to affect CD4+ T cell populations.

A European team fared better with cyclosporine A. In a nine-patient trial—and later, in a study of nearly 80 patients—



CHRIS BJORNBERG *Photo Researchers, Inc.*

OUT TO KILL: AIDS viruses bud off from an infected T cell. Because these immune cells enable HIV to replicate inside them, some researchers hope that tamping down an immediate T cell response to an infection might stop the virus.

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CD4+ T cell counts rose to normal levels after eight weeks of cyclosporine A and antiretroviral therapy, says immunologist Giuseppe Pantaleo of the University of Lausanne in Switzerland, a key investigator in the trials. "We were indeed surprised by the magnitude of the effect on the CD4+ T cells," he remarks.

Pantaleo's results stand in stark contrast to some previous attempts. In 1989 Canadian researchers attempted to treat patients with AIDS using cyclosporine, with unfortunate consequences. Not only did patients experience severe toxic symptoms from the treatment, but their T cell counts plummeted.

Hence, timing seems to be important with this kind of HIV therapy. "This is not, in my mind, an approach to take during chronic infection, because once infection has been established, the mechanisms of immune activation become much more complicated," observes Martin Markowitz, staff investigator at the Aaron Diamond AIDS Research Center in New York City. "I don't think that you want to intervene in a disease that is characterized by progressive immunosuppression with immunosuppression."

Markowitz and his colleagues instead hope to target HIV-positive patients in the early, acute stage. Because improvement in the CD4+ T cell count occurred shortly after patients took cyclosporine in previous studies, the team is using small doses of cyclosporine and a short, four-week treatment period, Markowitz says. Results of this trial of around 45 patients are expected toward the end of the year.

This novel line of attack against HIV is in its early days, and the scientific community is still cautious. But with antiretroviral resistance on the rise, immunosuppression could prove to be a much needed extra weapon in the anti-HIV arsenal.

Bianca Nogrady is based near Sydney, Australia.

Dashed Hopes

Disappointment tinged with determination is the feeling among HIV vaccine researchers following the failure of Merck's V520 vaccine, one of the most promising vaccine candidates. In contrast to the unusual approach of suppressing the immune system discussed in the accompanying text, the Merck vaccine—consisting of a disabled adenovirus carrying three key HIV genes—was designed to stimulate the immune system's killer T cells to attack HIV. In September, Merck ended the phase II clinical trial of 3,000 volunteers early when the drug failed to prevent infection or reduce viral loads in those who later became HIV-positive.

Although the failure is a significant blow, researchers have not turned their backs on a T cell–based vaccine just yet. Some of them suggest that a more potent T cell trigger may be needed, and another avenue being explored combines the T cell approach with stimulation of neutralizing antibodies against the virus.

STOCKBYTE/GETTY IMAGES (*ribbon*); DAVID DAVIS *Photo Researchers, Inc.* (*bottle*); EMILY HARRISON (*photoillustration*)

OLFACTION

Losing Scents

A pheromone-gene link raises questions about the decline of nasal know-how BY COCO BALLANTYNE

Freshly brewed coffee, rancid meat, the scent of a mother, an alarming waft of smoke—good or bad, smell is a powerful sense, capable of rousing remote memories, guiding behaviors and influencing moods. Scientists have long suspected that the immense diversity in human olfactory experience results at least partly from heredity, and now a research team has shown that the perception of specific odors can indeed be traced to one's genes. Beyond connecting the dots between genes and odors, these findings raise intriguing questions about human evolution. Our repertoire of functional olfactory genes has been shrinking over evolutionary time—and no one knows why.

Scientists at the Rockefeller University and Duke University have demonstrated that chemicals secreted in male sweat can smell like stale urine to one person, sweet flowers or vanilla to the next, or nothing at all to another, depending in part on which variant of an odorant receptor they have in their noses. The sweat chemicals investigated, androstenone and androstadienone, are particularly sexy odors because they are degradation products of the hormone testosterone.

"These chemicals are, in part, interesting because there is a link to potential human pheromones," says Hiroaki Matsunami, the molecular geneticist who led the Duke team in identifying and characterizing the receptors. Androstenone is a pheromone secreted in the saliva of male pigs that induces females to assume the mating stance, and androstadienone can drive fluctuations in stress hormones among women sniffing it.

For humans, detecting these compounds could be useful "if you're shopping around for the man with the highest level of testosterone," conjectures team member Leslie Vosshall of Rockefeller. But without more data, Vosshall says, it is impossible to know what role—if any—these chemicals play in human society.

Researchers suspect that the ability to smell these compounds—thanks in part to a receptor called OR7D4—served a more critical function in the past. The gene for the receptor exists in different forms: among the study's 391 human partici-

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pants, the majority had two functional copies of the *OR7D4* gene, but a substantial minority had at least one nonfunctional copy—meaning that a significant number of inoperative *OR7D4* variants swim through the gene pool. The presence of these apparently useless genes suggests that *OR7D4*'s importance has diminished, if not disappeared, among humans. When a gene's product provides no evolutionary advantage, mutations accumulate, and eventually that gene becomes inactivated. Natural selection may have relaxed its grip on *OR7D4*, allowing it to drift through human populations in both its intact and broken forms.

SMELLS LIKE ... VANILLA? Chemicals secreted in male sweat have different scents to different people, depending on the particular odor receptor each person has. Scientists have found a genetic link for the detection of two testosterone-derived chemicals, which are possible pheromones.

LOUIE PSIHOYOS *Corbis*

If this is the case, *OR7D4* is not alone. "We have been losing functional olfactory receptors for a long time," remarks Barbara Trask, director of human biology at the Fred Hutchinson Cancer Research Center in Seattle. And some of these losses began before humans diverged from other primates. By analyzing genetic sequences of different species, Trask and others have found that compared with mice, rats, dogs and other primates, people have a greater percentage of pseudogenes—defunct genes that arise through mutation—littering our olfactory genome.

No one knows why human olfaction has been circling the evolutionary drain; most likely, somewhere along the line, smell became less relevant to our survival and reproduction. One hypothesis is that improvements in eyesight shifted reliance away from our noses and onto our eyes. Yoav Gilad of the University of Chicago and his colleagues have shown that the gradual deterioration of functional olfactory receptors paralleled the acquisition of trichromatic (full-color) vision in humans and other primates. If sight replaced smell, it might have happened in many aspects of living, including foraging, courting, and detecting predators, Gilad speculates.

Other theories also try to explain the loss of olfaction, points out Andreas Keller, the Rockefeller geneticist working with Vosshall. For example, the evolution of upright walking brought our heads up, reducing the amount of time spent sniffing around on the ground for food, Keller says. Better verbal communication or improved intelligence may have also reduced the reliance on olfaction, Trask speculates.

Perfume makers may be disappointed to know that the gradual diminution of serviceable olfactory receptors appears to be continuing, according to genetic analyses. Still, the average human nose can detect some 10,000 odors. Not bad.

Coco Ballantyne is a freelance writer based in New York City.

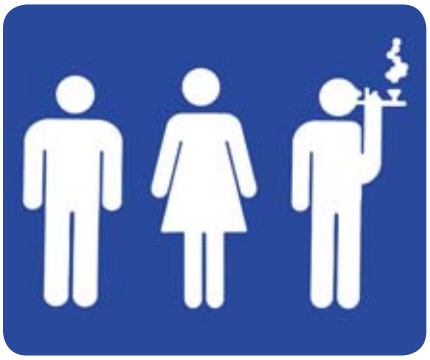
DRUG TESTING

A Stash in Every Flush

Chemical signatures in sewage may reveal the truth about drug use BY DAVID BIELLO

Our least precious bodily fluid may just tell the tale of our collective taste for illicit drugs, if a new technique for sampling sewage for evidence of their use proves effective. Scientists have developed methods for isolating the by-products of drug use that are excreted in urine.

"Sewage waters can be considered as a diluted, pooled urine sample," explains toxicologist Roberto Fanelli of the Mario Negri Institute for Pharmacological Research in Milan, whose group has employed mass spectrometry to analyze wastewater in urban rivers. The chemical target of Fanelli's study was benzoylecgonine—what the body turns cocaine into after the drug has done its brain-altering business. "We found that, sampling the Po River on different days in different months, the river carried the equivalent of about four kilograms of cocaine every day."



DRUG TESTING: Because urine contains breakdown products of absorbed chemicals, researchers feel that by testing sewage, they can accurately gauge patterns of drug use in a community.

EMILY HARRISON

Environmental chemist Jennifer Field of Oregon State University and her colleagues have used liquid chromatography with similar results. "Here's a new tool for taking snapshots of communities over space and in time and getting a less biased

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view of drug use" than would be obtained from traditional phone surveys, she says.

Already such snapshots have been taken of London, Milan and a wide range of communities of varying sizes in the U.S., including Corvallis, Oregon State's hometown. The U.S. Office of National Drug Control Policy (ONDCP) has taken an interest, running a pilot project in 2006 to test such methodologies in 24 facilities surrounding Washington, D.C. "We think if this can be shown to be reliable, it has value," says David Murray, chief scientist for the Counterdrug Technology Assessment Center at the ONDCP. "We know how many metric tons of cocaine are produced in the Andes, we know how many we seize on the open seas, but we don't know how many metric tons are consumed."

The ONDCP has no plans for further testing at this point, but both the National Institute on Drug Abuse (NIDA) and the Environmental Protection Agency may pursue it.

Sewage-sampling techniques, which can be applied to almost any drug, prescription or illicit, might be most useful in broadly identifying those strata of society who typically do not self-report recreational drug use or end up in the statistics kept by public drug abuse treatment facilities. "People have an incentive to tell government pollsters they don't use illegal drugs when asked," says Bill Piper, director of national affairs for the Drug Policy Alliance, a drug law reform advocacy group. The techniques could not, however, pinpoint actual individual drug users. "To get data from individuals, one should track samples close to the source at the time of toilet flushing, which is practically impossible," Fanelli says.

Having a broad view of chemical use could provide insight into how best to target limited drug treatment resources or to enable, for the first time, true comparisons

Sewage Standards

Although acquiring sewage samples for drug testing would be routine—wastewater treatment plants already test both inflow and outflow daily—standardizing analytical techniques will not be easy. Some sewage plants also treat storm runoff, which would dilute samples. Various preservation techniques might affect samples and even what the results actually signify. Finally, there is the tricky issue created by the amount of drugs an individual might consume, points out Wilson Compton, director of the Division of Epidemiology, Services and Prevention Research at the National Institute on Drug Abuse: "How can we reconcile a large amount of use by a small number of individuals versus a little bit of use from a large number of individuals?"

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between levels of drug use from city to city. It also might reveal the effectiveness—or lack thereof—of particular anti-drug efforts. "If law enforcement believes that they have eradicated the source of a substance for a community, this would be one way to verify those possibilities," says Wilson Compton, who is the director of NIDA's Division of Epidemiology, Services and Prevention Research.

Requests for such overall pictures are pouring in, according to researchers, from government facilities such as prisons and national labs to major cities. In November, Field and her colleagues took a snapshot of the state of Oregon on one day to assess the feasibility and validity of the liquid-chromatography method. And longer-term monitoring could quantify and confirm patterns. "You can see this upswing in the recreational use of cocaine" on the weekend, Field says, "as evidenced by increases in some cases starting as early as Thursday." As Guy Allen, plant operator at the Corvallis Wastewater Reclamation Facility, puts it: "It's always interesting to know what's in the sewage."

OPTICS

Glow for the Dark

New kind of night vision for the clearest images yet BY CHARLES Q. CHOI

In 1868 Swedish physicist Anders Ångström discovered that the sky always has a slight glow to it. The light emanates from molecules excited by sunlight or cosmic rays in the upper atmosphere. At night, the amount of airglow is comparable to the light from the full moon spread over the entire sky. But because most of it lies in the short-wave infrared range, the light remains largely invisible—at least to human eyes. Researchers have now devised a camera that could effectively detect this glow to see in the dark better than ever before.

Conventional digital imagers typically rely on silicon, and they do not detect nightglow. But sensors made with germanium, another common semiconductor, can. The problem is that growing germanium crystals using standard semiconductor techniques often leads to defects that can reduce the sensitivity of any resulting sensors. Making high-yield germanium sensors free of defects is very hard, driving up costs and limiting their widespread use.

While at Bell Laboratories, Conor Rafferty and Clifford King helped to invent a way to circumvent the imperfections while still using conventional semiconductor techniques. Germanium always develops some flaws when grown on silicon because the crystalline structures of the two elements do not line up well. These defects, however, only travel diagonally upward from silicon. The researchers found that they could grow germanium from silicon layers located at the bottom of microscopic cavities. As the flaws spread, they run into the walls of the pits, leaving defect-free germanium growing straight upward. "They've addressed a significant engineering challenge here," comments Errol Arkilic, a program manager at the National Science Foundation.

Rafferty and King originally developed their devices for long-distance telecommunications applications, which use short-wave infrared wavelengths as well. The telecommunications industry, however, crashed around 2001 just as they made their discovery. That spurred them to instead pursue imaging, and they founded NoblePeak Vision in Wakefield, Mass. The result of their work: the Tri-Wave nightglow vision camera, which sees in the visible, near-infrared and short-wave infrared. NoblePeak expects the device to reach the market next year.

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BETTER SEEING IN THE DARK: A thermal-vision camera can capture the infrared radiation from a person (*left*), but a camera made by NoblePeak Vision relies on invisible atmospheric nightglow to generate a much clearer image (*right*).

NOBLEPEAK VISION

The TriWave camera has advantages over current night-vision technologies, which include image intensification and thermal vision. Image intensification amplifies what visible light is available, meaning that systems using that approach would suffer under dark skies, whereas nightglow vision would not. Also, because pixels in an image-intensification system are linked, they can "bloom," or overload together, under bright light; in contrast, pixels in TriWave are electronically isolated, leading to zero blooming. Although thermal vision works in the dark—it relies on long-wave infrared—it cannot see through glass as nightglow vision can, nor can it read license plates or ID badges, because the writing on them is thermally indistinct from their backgrounds. Also, heat emitted from a person's face obscures details, making thermal vision unfit for identifying people.

The main drawback for relying on nightglow is that it does not penetrate ceilings or walls. But NoblePeak says that commercial infrared illuminators could shed enough invisible light for its goggles to work for any covert operations indoors. "Because distances indoors are short, you wouldn't need big illuminators," King points out.

NoblePeak intends to first target the security camera market, to help protect ports, airports, borders and power plants. The company also plans to aim for military applications, to perhaps field-test nightglow goggles by the end of 2008. The U.S. military has sought to exploit short-wave infrared wavelengths for night vision "for the last 50 years or so," King says.

"This could represent an innovation that allows for cost-effective deployment of a camera that works day and night sans illumination," Arkilic remarks. He also notes that NoblePeak was recently judged

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the most promising security technology start-up company in North America in the Global Security Challenge, which annually seeks to identify new enterprises in the security industry.

Nightglow vision could also have consumer and medical applications. It could enable drivers to see better at night, doctors to peer through the skull to look at blood flow, or dentists to see cavities in teeth without x-rays. "We hope to open a new window on the electromagnetic spectrum," Rafferty says.

Charles Q. Choi is a frequent contributor based in New York City.

AEROSPACE

Supersonic Pulse Power

Nazi-era weapons lead to fuel-stingy aircraft engines BY STEVEN ASHLEY

For nearly a year after Nazi Germany unleashed its V-1 flying bomb in June 1944, the early, crude cruise missile plagued English and Belgian cities and countrysides with its terrifying buzzing sound before raining down random death and destruction. Engineers are now refining the pulse jet, the simple but noisy and fuel-wasting power plant that propelled the buzz bomb, into a lightweight and powerful engine that relies on repeated shock wave–driven combustion cycles to produce thrust efficiently. In a decade or two, such pulse detonation engines could power many types of aircraft.

Pulse jets rank among the simplest of engines, explains Narendra Joshi, leader of a research group at General Electric in Niskayuna, N.Y. In many ways, the device resembles a combustion cylinder in a standard automobile engine, though without a piston. The basic recipe: Take a short metal tube and place injector valves at one end that can rapidly meter pressurized fuel and air into the tube on command. Then squirt in small amounts of fuel and air to create a flammable mixture and light it off with a spark plug. The resulting conventional fuel burn will generate expanding combustion gases that whoosh out the other end of the pipe, creating thrust. Now do it again—and again, 50 times a second (a frequency that produces the engine's infamous buzzing sound). Although the pulse jet is a simple and effective propulsion system, it consumes fuel comparative-

BUZZED: Germany's V-1 flying bomb relied on the pulse jet engine. Similar engines featuring much faster fuel combustion offer better performance and fuel efficiency.

ERIC LONG National Air and Space Museum (SI2004-60150)

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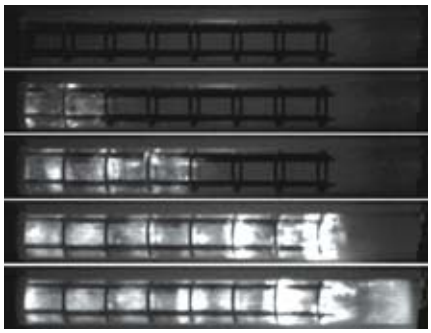

FUEL-BURN ACCELERATION down a tube achieves supersonic speeds to extract more work from a given amount of fuel.

ly slowly and incompletely, making the combustion process inefficient.

If, however, the fuel and air are injected and ignited so that the spark-generated flame front accelerates through the mixture to the end of a longer tube, the burn can reach velocities approaching five times the speed of sound. This highly efficient supersonic reaction causes such quick and complete combustion that the mixture essentially explodes, or detonates, which produces more work from the same quantity of fuel. The explosions in these pulse detonation engines are set to occur in intervals of several tens of milliseconds, more than twice as frequently as those in pulse jets.

By modeling the process's complex combustion behavior in computers and then matching the results against laboratory tests, researchers during the past decade have gained greater understanding of the underlying physics of pulse detonation. Meanwhile engineers have exploited those studies to develop prototype pulse detonation engines that could power supersonic, air-breathing missiles, boost orbital launch vehicles or augment fighter aircraft afterburners. But "the real pot of gold at the end of the rainbow" is a hybrid turbine–pulse detonation engine, according to Gary Lidstone, a Pratt & Whitney engineering manager based in Seattle. In such a system, pulse detonation tubes replace part of the central compressor and combustor (combustion chamber) of a gas turbine. This kind of design could significantly boost the fuel efficiency of the high-bypass turbofan while muffling the combustor's jackhammerlike noise.

Pratt & Whitney engineers have recently completed test-bed trials of a pulse detonation combustor that successfully burns jet fuel in a two-inch-diameter tube, even when subjected to the simulated back pressure from downstream turbine wheels. With support from NASA and the U.S. Air Force, the company is now gearing up to evaluate the technology's use in a hybrid engine that could be demonstrated in flight within the coming year. In the meantime, Joshi's group at GE is taking a pulse detonation combustor that features three two-inch tubes and marrying it to a six-inch-diameter, 100-horsepower turbine—a fuel-flow starter from an A-10 Warthog attack plane.

Joshi warns that many challenges remain to be addressed, including developing ultrarobust, fast-acting valve and control systems, as well as components that resist the severe mechanical fatigue from pulsed combustion and combustion tubes that fit inside a standard turbine. But if engineers can surmount such obstacles, then hybrid engines might cut fuel consumption by 5 percent or more, saving aircraft operators millions of dollars in refueling bills annually and reducing carbon dioxide emissions. Such benefits could certainly send human pulses racing all over the aerospace community.

Shocking Spin-off

In addition to finding ways to power aircraft, engineers have turned their basic understanding of pulse detonation engines to creating offshoot products designed to clean the hard-to-remove ash that fouls the insides of heat-transfer tubes in industrial boilers. Pratt & Whitney's Shocksystem and GE's Powerwave+ remove stuck-on soot deposits with shock waves created by pulse detonation.

GE GLOBAL RESEARCH

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VIRULENCE

Deadly Orbits

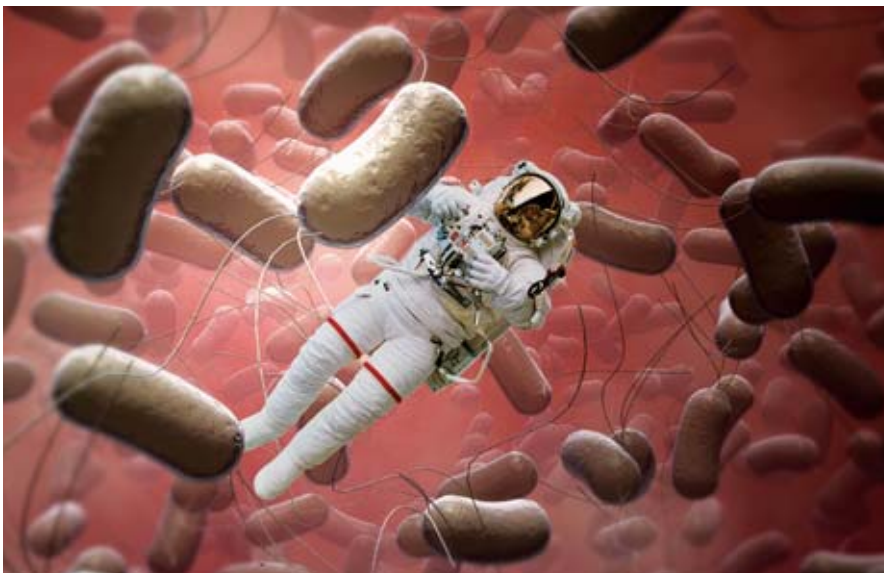
Why a voyage to space increased a bacterium's killing power BY DON MONROE

News that *Salmonella* bacteria came back from a trip to outer space deadlier than before sparked headlines earlier this fall. It might seem like fodder for a science-fiction thriller, but such temporary changes are par for the course when bacteria encounter new environments—and researchers have seen it before without the need for a rocket ship.

"These are not mutated bugs from space," emphasizes Cheryl Nickerson of Arizona State University, who led the team that sent the cultures onboard the space shuttle in September 2006 and reported the work in the *Proceedings of the National Academy of Sciences USA*. "The bacteria aren't doing anything new." Instead, she says, the space environment acted to "globally reprogram how the bacteria regulated the expression of their genes" and thus the levels of various proteins, enabling the bacteria to adapt to the changing conditions.

Near weightlessness was not the actual trigger for the bacteria. The force of gravity on a tiny microbe is trivial compared with the constant buffeting by its watery surroundings. Without gravity or other disturbances, however, liquid in a growth flask becomes very still. Nickerson and her colleagues have previously simulated this "low-fluid-shear" culture environment in the laboratory by using a gently spinning vertical disk that keeps the bacteria suspended. As early as 2000, they found that *Salmonella* Typhimurium, which causes temporary food poisoning in people but fatal typhoid fever in mice, becomes more virulent after growing in this simulated microgravity.

The researchers wanted to see if the same thing would happen in space. To find out, they grew *Salmonella* simultaneously on the space shuttle and in a special chamber at the Kennedy Space Center that mirrors the conditions on the shuttle except for the low gravity. They inoculated mice with bacteria from a batch from each location within hours of landing and found that the space travelers were about three times as deadly.



SPACE THREAT? Low fluid motion, which can occur in a spacecraft, can cause *Salmonella* to become more virulent, potentially raising an astronaut's risk of infection.

James Wilson, a colleague of Nickerson's, says that they also found that gene expression, or transcription of DNA into RNA, differed significantly for 167 different genes. Of these, an "overwhelming" one third responded to a single RNA binding protein called Hfq. Many of these genes also come into play when *Salmonella* forms biofilms, hardy complexes that resist antibiotics and immune defenses. "What we might have been seeing," Wilson says, "was the initial stages" of biofilm formation.

The underlying cellular personality changes might be even more dramatic than they appear, remarks Michael Surette, who studies gene expression in *Salmonella* and other bacteria at the University of Calgary in Alberta and was not involved in the study. He suspects that local regions of the unstirred space culture will develop different conditions. The overall effect could mask much larger changes for bacteria within these pockets. "The change in virulence to me is more striking than the change in gene expression," Surette adds.

As yet scientists do not know whether increased virulence threatens astronauts. But, Nickerson says, "there's no question that this low-fluid-shear culture environment is a critical environment that cells can sense and respond to." Because bacteria also experience low-shear conditions in sheltered corners of the digestive or reproductive tracts, she hopes that targeting Hfq could slow *Salmonella* infection, so that the exotic space-based experiments could help patients on Earth. "Some of our biggest advances in understanding how biological systems operate have come when we have studied those biological systems in extreme environments."

Don Monroe is based in Berkeley Heights, N.J.

NASA Photo Researchers, Inc. (astronaut); MEDICALRF.COM/CORBIS (bacteria)

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BIOLOGY

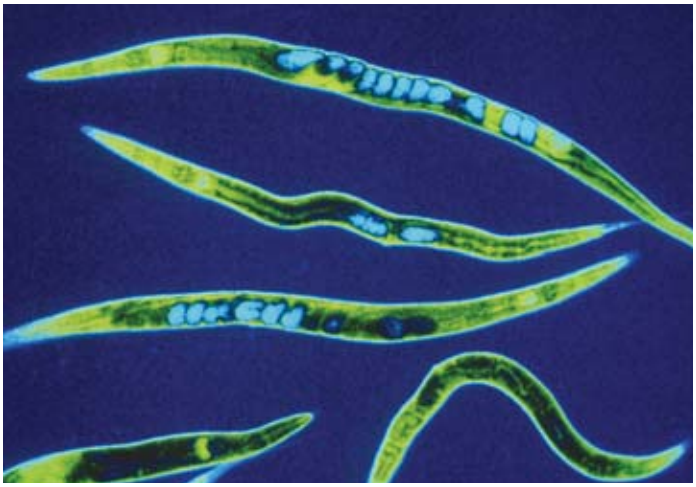
Evolution in a Petri Dish

In the lab, seeing how infectious disease triggers new species BY LUIS MIGUEL ARIZA

In the 1930s the geneticist J.B.S. Haldane offered an explanation of why the gene for sickle-shaped red blood cells, which can produce lethal anemia, persisted in tropical populations. He suggested that the mutation offered a trade-off: although the sickle cells raised the risk of death, they also made a person one tenth as likely to contract malaria—a boon in the mosquito-ridden tropics. His striking idea that an infectious disease can drive evolution can now be directly tested in the laboratory with complex creatures, as reported this summer by Spanish researchers in the *Proceedings of the National Academy of Sciences USA*.

The team, led by José Luis Martínez, a microbiologist at the Spanish National Center of Biotechnology, and Alfonso Navas, director of the National Museum of Natural Sciences in Madrid, used tiny worms known as *Caenorhabditis elegans*, a species commonly used as a laboratory model. In 2001 the researchers wanted to check how the worms are normally killed in minutes by the infectious bacterium *Pseudomonas aeruginosa*. After only a week they found that one petri dish out of 152 was crowded with survivors. "At the beginning, we thought it was a mistake," Navas says. Subsequent experiments showed that the mutants were not only immune to the bacteria but also subsisted on them. "It is like saying: 'I am not only able to resist the infection, I also eat the killer,' " Navas explains.

Although experimenters have reported spontaneous mutations in viruses and bacteria, such rapid changes are rarely advantageous in complex animals. Most mutations instead prove lethal, so they do not persist. That is not the case in *C. elegans:* Navas now has thousands of mutants since the first examples of their class popped up six years ago. Under the microscope the normal worms thrive in a gran-



NEWBIE NEMATODE: In the lab, microscopic worm *C. elegans* almost evolved into a separate species that could resist deadly bacteria.

ulated forest of the bacterium *Escherichia coli*—twisting and vibrating in electric movements. The descendants of the mutants, on the other hand, exhibit a distinct behavior: unhurried, wriggling almost with caution. "It is evolution, and it is happening," Navas says.

The difference in the worms' movements shows that the ability to survive bacteria does not come without cost. The mutated individuals breathe poorly—they consume 30 percent less oxygen—and they are not as fast as their wild cousins in competing for food. The mutant strains can survive the poisonous bacteria probably because they are using alternative respiration enzymes. From a Darwinian perspective, Martínez says, the phenomenon represents a "second-class selection" that resembles the utility of the sickle cell mutation against malaria.

These worms have not fully evolved into a separate species, Navas concedes, but they seem close. The researchers have noted at least seven changes in proteins between the two groups—a condition sufficient enough in other nematodes to distinguish them as separate species. The differentiation of populations is the first step, and the worm experiment offers a good glimpse of how a new species emerges. "Watching speciation in the laboratory," Navas remarks, "is not science fiction" anymore.

Luis Miguel Ariza is a science writer and novelist based in Madrid. His latest novel, first published in Spain, is a scientific-religious thriller, The Lazarus Project *(Random House, 2007).*

Evolutionary Evidence

A 2006 poll by Michigan State University showed that one in three U.S. adults rejects the concept of evolution causing speciation—a contrast to the citizens of other countries (at least 80 percent in Iceland, Denmark, Sweden and France and 78 percent in Japan accept the concept). The problem may partly be that evolution occurs over geologic timescales, a span that can be difficult to grasp. Research that shows microscopic worms on the verge of speciation provides evolution with experimental evidence—evidence that creationism does not have. "To my knowledge, it is the first time that an evolutionary law has been demonstrated" in a complex creature, says José Luis Martínez of the Spanish National Center of Biotechnology.

JAMES KING-HOLMES *Photo Researchers, Inc.*

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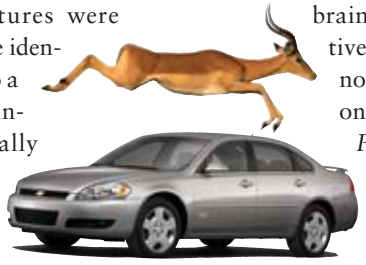
PERCEPTION

Eye on the Tiger

Apparently, keeping an eye on a real impala is easier than focusing on a Chevy Impala. Because monitoring predators, prey and people was a life-or-death matter for humans during evolution, researchers investigated whether people were more likely to pay greater attention to animals than to anything else. The scientists rapidly flashed photographs of natural scenes at volunteers. These pictures were shown in pairs that were identical, save for a change to a single object. The volunteers proved substantially faster and more accurate at detecting alterations involving animals—including other humans—than inanimate objects, even if the animals were small, peripheral and blended into the background. This result even proved true with vehicles, which the volunteers had presumably spent years watching for life-threatening changes in trajectory. Visual priorities of our hunter-gatherer ancestors evidently remain embedded in the modern brain, regardless of how relatively useless they often are now, the scientists reported online September 24 in the *Proceedings of the National Academy of Sciences USA*.



—*Charles Q. Choi*

LANGUAGE

Use It or Lose It

Words used the most evolve the slowest. Researchers have traced how past tense forms of English verbs have died out since the time of *Beowulf*. Only one persists as a rule: adding "-ed" to denote the past tense (so-called regular verbs). The investigators catalogued all the irregular verbs they came across, such as "sing"/"sang," as well as those that have since been regularized (such as "slink," which is now "slinked" but 1,200 years ago was "slunk"). Only 98 of the 177 irregular verbs they found have not been regularized, and given two verbs, if one was used $^1/_{100}$ as frequently, it evolved 10 times faster. Next to fall, they predict: "wed," the past tense of which will regularize to "wedded." The October 11 *Nature* published this study, as well as a similar one comparing soundalike words across Indo-European languages.

—*Nikhil Swaminathan*

PHYSICS

Not So Neutral Neutron

The neutron may be electrically neutral overall, but physicists had thought it was actually positively charged at its center with an offsetting negative charge at its outer edge. New results from three different particle accelerators suggest the neutron is even more complicated, with a negative charge both in its inner core and in its outer edge and with a positive charge sandwiched in between. The findings could improve understanding of the strong force, which binds atomic nuclei together, as well as the inner workings of stars. It might also have applications in nuclear energy and nuclear weapons. According to researcher Gerald Miller of the University of Washington, the neutron could prove even more complex as more data come in, as he describes in the September 14 *Physical Review Letters*.

—*Charles Q. Choi*

Data Points

Hole Shrinkage

Ozone in the stratosphere blocks deadly ultraviolet rays from the sun, but the past use of chlorofluorocarbons (CFCs) in aerosols and other products has thinned the protection. The damage is embodied by the infamous "ozone hole" that forms over the South Pole every Antarctic spring. (A hole is defined as a thickness of ozone less than 220 Dobson units—or less than 2.2 millimeters thick if the ozone resided at sea level at 0 degrees Celsius.) Measurements of the hole taken by the European Space Agency's Envisat satellite do not necessarily mean that the ozone layer has begun recovering. Rather weather patterns allowed warm air to mix into the polar regions, thus limiting the problem.

Temperature below which ozone depletion occurs:
–78 degrees C

Percent that the ozone layer has thinned every year this decade: 0.3

Peak Antarctic ozone loss, in metric tons:
In 2006: 40 million
In 2007: 27.7 million

Minimum ozone depth in hole, in Dobson units:
In 2006: 100
In 2007: 120

Area of hole, in square kilometers:
In 2006: 28 million
In 2007: 24.7 million

Area of North America, in square kilometers:
24.25 million

SOURCE: European Space Agency announcement, October 3

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RICHARD DU TOIT *Minden Pictures (impala)*; GENERAL MOTORS (*car*); ILLUSTRATION BY MATT COLLINS

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In Brief

THE 2007
NOBEL PRIZES

The awards feature a rarity—scientists won the Peace Prize, the first time since 1995. Two of this year's Nobelists have written for *Scientific American:* Mario Capecchi and former vice president Al Gore—three if you count the Intergovernmental Panel on Climate Change (IPCC).

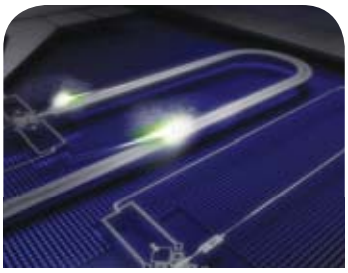
Physiology or Medicine: Mario Capecchi of the University of Utah, Martin Evans of Cardiff University and Oliver Smithies of the University of North Carolina at Chapel Hill, for their discoveries leading to gene targeting in mice. This "knockout" process inactivates individual genes to reveal their true functions.

Physics: Albert Fert of the University of Paris-South and Peter Grünberg of the German Research Center in Jülich, for their discovery of giant magnetoresistance, in which weak magnetic changes could cause big differences in electrical resistance. The iPod and other hard-drive devices owe their existence to this effect.

Chemistry: Gerhard Ertl of the Fritz Haber Institute of the Max Planck Society in Berlin, for his development of methods to study surface reactions—crucial for insights into many processes, such as the rusting of iron, the reactions that produce artificial fertilizers and even the destruction of the ozone layer.

Peace: The IPCC and Al Gore, for their efforts to spread knowledge about human-induced climate change and to lay the foundation to combat it.

QUANTUM COMPUTING
A Qubit Bus



GET ON THE BUS: Researchers have made a bus—here, a curved wire—to transmit qubits.

Two teams have forged the first chip-based version of a quantum bus, a tool for mixing and swapping information between qubits. The bus is a squiggly wire between two superconducting loops, which served as qubits. When activated, a qubit loop transfers its superposition to the wire in the form of a microwave photon. Raymond Simmonds of the National Institute of Standards and Technology in Boulder, Colo., who led one of the teams, got a seven-millimeter-long wire to store a photon for more than one microsecond. Rob Schoelkopf of Yale University and his group performed a similar trick with a longer wire that mixed a single quantum state between two qubits. To make a quantum computer, though, the researchers will have to keep the superconducting qubits stable or coherent for longer periods. —*JR Minkel*

NEUROBIOLOGY
Punishment for Harmony

Punishment may explain why most people live together in relative tranquility, according to the behavior of 23 male students who played an "ultimatum game." Each participant could split a sum of money however he chose with an anonymous partner. In some cases, the recipient had to accept any offer made; other times, after an offer was made, the recipient could penalize the giver by taking some or all of his money. Brain scans of the giver revealed that two areas were particularly active when punishment was an option: the lateral orbitofrontal cortex, a region previously implicated in processing a threat stimulus, and a section near it called the dorsolateral prefrontal cortex, involved in impulse control. Next, the University of Zurich team that conducted the study intends to test patients suffering from antisocial anxiety and personality disorders to determine if their behaviors result from a lack of impulse control or a poor assessment of punishment. Scan the October 4 *Neuron* for the study. —*Nikhil Swaminathan*

SYNTHETIC BIOLOGY
Something to Remember

Synthetic biologists have installed a genetic feedback loop in yeast, the first of these circuits to be built in a eukaryotic cell (one with membrane-bound structures, such as a nucleus). The loop consisted of two novel genes. When exposed to the sugar galactose, the yeast cell would activate the first implanted gene; that gene in turn would create a transcription factor that switched on the second gene. The second gene would then manufacture its corresponding transcription factor, which was designed to ratchet up the activity of the same gene that created it. Because of this looping effect, the second gene kept making its transcription factor even when galactose was eliminated from the cell's environment, effectively sustaining the memory of galactose exposure. Cells with such feedback designs could be jury-rigged to record past environmental conditions or quantify DNA damage. The report appears in the September 15 *Genes & Development.* —*Nikhil Swaminathan*

AP PHOTO (*Nobel medal*); ILLUSTRATION BY MICHAEL KEMPER, COURTESY OF NIST (*quantum bus*); HANS NELEMAN *Getty Images* (*officer*)

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SciAm Perspectives

Enough Hot Air Already

To slow climate change, it's time to talk about real action

BY THE EDITORS

When U.S. President George W. Bush urged the world's biggest emitters of greenhouse gases to follow his administration's lead in confronting climate change at the end of September, listeners could easily view the speech as a lot of hot air about a lot of hot air. After all, during most of President Bush's time in office, he has consistently cast doubt on any human role in global warming and rejected the international Kyoto Protocol on reducing such emissions as an unacceptable drag on economic development. But even if the president's newfound interest in cutting greenhouse gas releases is directed at voters who will elect his replacement next year, his change in attitude—though long overdue and still maddeningly provisional—could at least mark the start of a genuine solution to this looming problem.

The world's nations will soon meet in December on the Indonesian island of Bali to prepare the ground for a fully inclusive successor to the Kyoto treaty, one with enforceable limits on greenhouse gas discharges. If President Bush and the leaders of other Kyoto nonparticipants can finally bring themselves to act responsibly enough to truly face the threat, substantive progress could be made.

A window of opportunity for avoiding the worst effects of climate change still hangs open, but that window is fast slamming shut. Most scientists believe that we must restrict rises in the average global temperature to less than two degrees Celsius above preindustrial levels. But the business-as-usual track currently followed by the U.S. could take Earth's atmosphere to more than twice that increase by 2100, so any delay just makes the task harder.

Beyond the increasingly obvious damage to the natural world, climate change threatens to reverse the last two centuries of human advancement within our lifetime. A greater incidence of storms, floods, droughts and extreme climate swings could close the existing poverty trap on millions of the globe's most vulnerable people. For publicizing such perils, former vice president Al Gore, in his film *An Inconvenient Truth,* and the United Nations's Intergovernmental Panel on Climate Change have recently been awarded the Nobel Peace Prize.

MATT COLLINS

Our planet needs effective political leadership. To have a realistic chance of avoiding dangerous atmospheric warming, scientists say, developed nations need to slash greenhouse gas emissions by 50 to 80 percent of 1990 levels by 2050. A voluntary set of so-called aspirational goals negotiated on a country-by-country basis, such as those advocated by the present U.S. administration, simply will not do the trick. And without binding international restrictions, reluctant developing countries, already responsible for half the world's total greenhouse gas production, will continue to hold back.

Nearly one out of two Americans now believes that global warming is either already having dangerous impacts on people around the world or will in the next decade—a 20 percentage point increase since 2004, according to a recent survey by the Yale Project on Climate Change, Gallup and the ClearVision Institute. Further, 40 percent say that a presidential candidate's position on the issue will strongly influence how they vote. President Bush has clearly taken notice, but that newly acquired awareness has so far failed to translate into meaningful action.

Three steps need to be taken. Industrialized nations first must make deep, early and mandatory cuts in emissions. For the U.S., that ought to mean instituting carbon taxes, which would be the most straightforward way to create incentives while avoiding unfair partisan favoritism. But given that most legislators regard carbon taxes as political suicide, the government should establish a national cap-and-trade market. In such a system, international negotiators would set a countrywide cap on carbon releases, and carbon emission credits representing the total under that limit would be auctioned off to emitters, who could then trade the credits on the open market to meet their individual obligations at the lowest cost. Even the American business community is starting to come around to the idea of such restrictions as it begins to envision the huge boost they would provide to the domestic banking and green technology industries. The article on page 70, "Mak-

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ing Carbon Markets Work," by David G. Victor and Danny Cullenward, discusses both these options and how they could be implemented fairly and effectively.

Second, all nations should invest significantly more in new technology—especially in the development of carbon capture and storage methods—to stabilize the amount of climate-warming gases in the atmosphere. Government action on this front will be necessary because even well-intentioned efforts by private industry are bound to fall short.

Last, rich countries should establish a Marshall Plan–like program to help finance the transfer of the low-carbon technologies that developing countries need to grow their economies while emitting fewer greenhouse gases. Instead of targets for cuts, developing countries should be given incentives to lower atmospheric releases, perhaps by rewarding them with energy development aid when emissions fall below certain levels.

Talk is cheap. It's time for politicians to stop spewing hot air and start enacting hard limits on dangerous emissions. ■

THE EDITORS' BLOG

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Hillary Brings Up Science, but Will It Stay in Play?

Posted by Nikhil Swaminathan, Oct. 8, 2007

Save for the media swarm in the wake of the hand raises by Republican candidates Sam Brownback, Mike Huckabee and Tom Tancredo, it appears Hillary Clinton is the first to put science in the spotlight in the race for the White House.

Speaking on the 50th anniversary of the Sputnik launch last Thursday at the Carnegie Institution for Science, Clinton took the opportunity to talk about Bush's less publicized war—the one on science. She also released, via her Web site, an "Agenda to Reclaim Scientific Innovation."

She covered all the highlights of science and policy: stem cells, the mess at the FDA, budget woes (at agencies from the NIH to DARPA), space exploration (both manned and unmanned), climate change and renewable energy. While these issues are likely not new to readers of this publication and other science-savvy individuals, it's heartening to see them introduced on the political stump.

Of course (and here's my cynical streak erupting from my bile-filled belly), this speech was at the Carnegie Institution for Science. What was she going to talk about? Tax cuts for the rich?

Within the context of the entire Clinton campaign, this is something Chris Mooney, author of *The Republican War on Science,* and his colleague Matt Nisbet would call "framing." Hillary's platform is no doubt broad and has primarily focused on Bush's more well-known war, health care, education reform and whether or not she wants to powwow with some of the more controversial world leaders in power today. But on this day, she chose to focus on science.

Rather than framing, I call this "playing to the crowd." (I will consider calling it framing as soon as Mooney and Nisbet admit they are writing a book about framing in the Gladwellian mold, which, lucky for them, a recent *Wired* article can help them title and turn into a cash cow. For those interested,

continued on page 44

Sustainable Developments

Meaningful Goals for Climate Talks

Step-by-step advances, not grand gestures, offer the most realistic way to control greenhouse gases

BY JEFFREY D. SACHS

Governments of the world are now launching climate change negotiations for after 2012, when the Kyoto Protocol expires. World leaders acknowledge that civilization is on a dangerous course. Yet there is still little consensus about how to achieve stabilization of greenhouse gases.

We suffer no shortage of ideas about the instruments of action. For example, the world's governments could impose taxes on carbon emissions that are high enough to choke off the use of fossil fuels in favor of higher-cost but cleaner alternatives. Or they could impose a system of tradable permits that would have the same effect. The problem is not mainly with the instruments but with their unknown costs and benefits. We know we need to act immediately, but because of big uncertainties regarding key technologies, we cannot precisely calibrate the costs and benefits of alternative actions.

It is a little early to count on plug-in hybrids delivering 100 miles per gallon.

The biggest obstacle is that the most promising scalable technologies, such as carbon capture and sequestration (CCS) and plug-in hybrid vehicles, are close to introduction but not quite there yet. China and India probably will not bet their future on CCS until the technology is proved, yet neither country has even one demonstration plant. Similarly, it is a little early to count on plug-in hybrids delivering 100 miles per gallon, a goal well within reach, until the first one rolls off the assembly line, with batteries that are safe, efficient, long-lasting and reliable.

How then can the world agree on meaningful targets and avoid a 10-year squabble or empty gestures? Rather

BRUCE GILBERT/EARTH INSTITUTE

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continued from page 42

myself included, Mooney will be further breaking down the elements—or frames—of the speech all week on his blog.)

But leaving the semantic discussion on framing, I am more concerned with whether this speech will just fade away to the bottom of Clinton's bullet-point list of stances or whether such a strident call to arms will necessitate others (both Democrat and Republican) to refine their ideas about the role science plays in the next election.

I would like to see some alternative options to Clinton's proposals from other candidates because, frankly, this is a topic that's important to me. There is plenty here to tweak, massage or offer alternative ideas to: the issue of manned versus unmanned space exploration, new ideas for improving science education, how to increase the number of women pursuing science degrees, and so on. The hope is that the Obamas and Edwardses (and to a less likely extent the Giulianis and Romneys of the world) won't just say, "Hey, that sounds good, just fold all that business Hillary was talking about into my campaign, as well."

But will anyone step up and take what Hillary has proposed and run with it? Will Hillary even mention the subject in similar breadth and depth when it's not a significant scientific anniversary and she's not standing in front of a group of researchers?

With all the aforementioned highlights, it seems as though, if science and technology are going to have their day in the political arena, now would be the time. Hell, just days before Clinton's speech, Michael Griffin, NASA chief, admitted that China will likely beat the U.S. back to the moon. Do we have to wait another 10 years for another communist country to beat us to a space goal before we reprioritize science in our culture? (That last time really served to chap our collective hide.)

If no one else in either party puts their chips down, remember New York mayor (and rumored independent presidential candidate) Michael Bloomberg has been there, done that.

Hey, Hillary, can you say "running mate"?

than aiming for a single grand outcome from the new round of negotiations, we should proceed in meaningful steps, taking ground where we can at known low cost and aggressively proving the new technologies that we will need. For example, it would be possible now to seal an international agreement in which the rich countries will pay the poorest countries not to cut down their forests, because the evidence is very clear that most deforestation can be avoided at low cost (perhaps $10 per ton of avoided carbon dioxide) and with enormous global ecological benefits.

It would also be possible for the major coal-producing regions to agree to adopt several demonstration projects of CCS technology in the power sector. On average, each of these CCS power plants will require around $300 million to $500 million over 10 years beyond the cost of a conventional plant. China and India are prepared to introduce these unproved, more expensive yet cleaner technologies if the U.S., Japan and Europe help to pay for them. An agreement on financing at least two large-scale CCS projects in India and China could be achieved within the next few months.

A third area of agreement would be a worldwide public-private partnership on plug-in hybrids. A major global effort on battery design could provide the key technological breakthrough needed. A coordinated policy effort could help each region to prepare its power grid for a massive introduction of this new technology within the next five to 10 years. A fourth area would be shared, binding commitments to scale up the adoption of existing low-emissions technologies, such as hybrids, diesel automobiles and energy-efficient lighting. These can be achieved by agreeing to impose standards on industries (for example, setting maximum emissions per passenger mile on new automobile sales) while leaving the precise choice of technologies for meeting those standards to the marketplace.

It is also within our grasp today to agree on overarching principles: that the world will aim to stabilize greenhouse gas emissions at safe levels no later than 2050; that countries will work together to develop and disseminate scalable low-emissions technologies; that the rich nations will pay for the bulk of research, development and demonstration and make the technologies available for global use equitably; and that the world will agree on progressively tighter and binding targets and market prices on emissions, as scalable low-cost, low-emissions technologies are developed and demonstrated.

Such a step-by-step approach will not produce a grand bargain in a single swoop. Instead it could demonstrate concrete and meaningful actions from the very start—and without years of wrangling. Within five years, there would be an excellent chance that proved, scalable and inexpensive technologies could support even bolder targets for greenhouse gas stabilization. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

SCI AM An expanded version of this essay is available at **www.SciAm.com/ontheweb**

MATT COLLINS

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Forum

Our Evolving Present

Human changes to the environment are accelerating evolution in many ecosystems

BY ROB DUNN

The cane toads go bump in the night. I hear them banging as they misjudge where my hotel door ends and the forest begins. The force of a large toad knocking wood is substantial. But the force with which the toads, which are native to Central America, have hit Australia is even greater. Brought to Queensland in 1935 to combat beetles infesting sugarcane fields, the toads have spread out from their point of entry like the shock waves of a bomb, warty legs and oversize tongues jettisoned into every conceivable ecological crack.

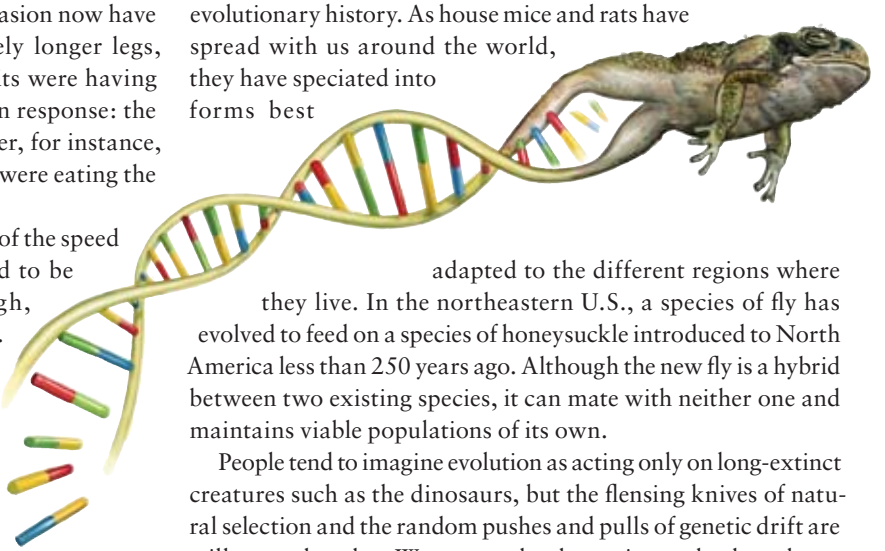
Recent research by Ben Phillips and his collaborators at the University of Sydney has shown that the toads are evolving as they spread, perfecting their ability to adapt to the Australian landscape. The toads at the front edge of the invasion now have smaller bodies, reduced toxicity and relatively longer legs, apparently because individuals with those traits were having greater success. The native fauna has evolved in response: the mouths of some snake species are getting smaller, for instance, because so many of the snakes with big mouths were eating the poisonous cane toads and dying off.

Such examples are changing scientists' views of the speed of evolution. The process was long considered to be slow, even lumbering. Increasingly, though, researchers are observing evolution in action. You may be familiar with the examples of the evolution of drug-resistant bacteria or agricultural pests. Microbes and pests may change the fastest, but they are not unique.

We see rapid evolution most often where some force (often us) has given it a jump start by suddenly and dramatically altering an organism's environment. Rats have developed smaller bodies when introduced to islands. Trophy fish have also adopted smaller body sizes in response to fishers' preference for big fish (which, if killed, do not breed). Mayflies in streams where trout were released now forage at night to avoid the fast-swimming predators. Many hundreds of herbivorous species have switched to novel, sometimes toxic, food sources introduced by humans and have come to specialize in consuming those new resources. Various native species have evolved in response to newly arrived competitors. Cedar trees have begun making toxins to protect themselves from being eaten by deer now roaming in their formerly benign habitats. Mussels in New England have evolved the ability to detect invasive green crabs and produce thicker shells where the crabs are present.

Most of these changes appear to have resulted from natural selection: organisms that by chance had some genetic trait that helped them thrive in the face of a new stress were favored, and subsequently they reproduced successfully and spread the helpful trait to future generations. But some evolutionary changes we see may simply be the result of genetic drift (random genetic changes that accrue over time).

The more we look, the more we can observe evolutionary changes that are fast enough to be seen during the course of a single study. A Ph.D. student might, in the five or so years of a dissertation project, realistically see the development of new species, whether in real time or using genetic tools to reconstruct evolutionary history. As house mice and rats have spread with us around the world, they have speciated into forms best adapted to the different regions where they live. In the northeastern U.S., a species of fly has evolved to feed on a species of honeysuckle introduced to North America less than 250 years ago. Although the new fly is a hybrid between two existing species, it can mate with neither one and maintains viable populations of its own.



People tend to imagine evolution as acting only on long-extinct creatures such as the dinosaurs, but the flensing knives of natural selection and the random pushes and pulls of genetic drift are still at work today. We see a red oak tree in our backyard or a cane toad at our hotel-room door, but the names fool us. These species are not the same this year and next. Although the evolution we observe in real time will not suddenly give us dinosaurs, it is still a process to be reckoned with. Give natural selection a few individuals of any species, and it will work the same way in a waste pool as it does in Yellowstone National Park. Nature abhors a vacuum, but nearly anything else will do. ■

Rob Dunn is an ecologist in the department of zoology at North Carolina State University. He studies the evolutionary relationships between animals and plants and the response of species to climate change.

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Skeptic

An Unauthorized Autobiography of Science

Journal article explanations of how science works often differ from the actual process

BY MICHAEL SHERMER

According to 55 percent of 350,000 people from 70 countries who participated online in Richard Wiseman's Laugh Lab experiment (discussed in last month's column), this is the world's funniest joke:

> Two hunters are out in the woods when one of them collapses. He doesn't seem to be breathing, and his eyes are glazed. The other guy whips out his phone and calls the emergency services. He gasps, "My friend is dead! What can I do?" The operator says, "Calm down. I can help. First, let's make sure he's dead." There is a silence, then a shot is heard. Back on the phone, the guy says, "Okay, now what?"

So say the data, but according to Wiseman's personal narrative describing how the research was actually conducted (in his new book *Quirkology*), he believes that "we uncovered the world's blandest joke—the gag that makes everyone smile but very few laugh out loud. But as with so many quests, the journey was far more important than the destination. Along the way we looked at what makes us laugh, how laughter can make you live longer, how humor should unite different nations, and we discovered the world's funniest comedy animal." Chickens notwithstanding, such first-person accounts in popular science books that include the journey and not just the destination afford readers a glimpse into how science is really carried out.

Formal science writing—what I call the "narrative of explanation"—presents a neat and tidy step-by-step process of Introduction-Methods-Results-Discussion, grounded in a nonexistent "scientific method" of Observation-Hypothesis-Prediction-Experiment followed in a linear fashion. This type of science writing is like autobiography, and as the comedian Stephen Wright said, "I'm writing an unauthorized autobiography." Any other kind is fiction. Formal science writing is like Whiggish history—the conclusion draws the explanation toward it, forcing facts and events to fall neatly into a causal chain where the final outcome is an inevitable result of a logical and inevitable sequence.

Informal science writing—what I call the "narrative of practice"—presents the actual course of science as it is interwoven with periodic insights and subjective intuitions, random guesses and fortuitous findings. Science, like life, is messy and haphazard, full of quirky contingencies, unexpected bifurcations, serendipitous discoveries, unanticipated encounters and unpredictable outcomes. This chaotic process helps to explain, in part, the phenomenal success in recent decades of first-person popular accounts by scientists of how they actually did their research. The effect is especially noteworthy in works exploring the peculiarities of life.

Steven Levitt and Stephen Dubner's *Freakonomics* (William Morrow, 2006) illuminates the power of incentives through certain oddities. For instance, that most drug dealers live with their mothers because only the top guys make the big bucks while the rest bide their time and pay their dues, or that baby names tell us about the motives of parents. Cornell University professor Robert Frank's *The Economic Naturalist: In Search of Explanations for Everyday Enigmas* (Basic, 2007) employs the principle of cost-benefit analysis to explain such idiosyncrasies as why drive-up ATM keypads have Braille dots (because it is cheaper to make the same machine for both drive-up and walk-up locations), why brown eggs are more expensive than white eggs (because there is less demand and the hens that lay them are larger and consume more food), why it is harder to find a taxi in the rain (because more people use them when it is raining, most cabbies reach their fare goals earlier in the day), and why milk is stored in rectangular cartons but soft drinks come in round cans (because it is handier to drink soda directly from a round can but easier to pour and store milk in a rectangular carton).

In my October column I railed against the artificial (and odious) ranking of technical science writing over popular science writing. I suggested that the latter should be elevated to a more exalted standing of "integrative science," where good science writing integrates

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data, theory and narrative into a useful and compelling work. And here I would add that exploring the minutiae of life, especially on the quirky borderlands of science, makes the scientific process more accessible to everyone. Where a narrative of explanation might read something like "the data lead me to conclude…," a narrative of practice reads more like "Huh, that's weird…."

Weirdness trumps data in the biography of science. ■

Michael Shermer is publisher of Skeptic *(www.skeptic.com). His latest book is* Why Darwin Matters.

Anti Gravity

Apples and Cheese

A write-up of my week as a writer not writing

BY STEVE MIRSKY

During the first week of October, I was the science-writer-in-residence at the University of Wisconsin–Madison. Being a science-writer-in-residence vastly beats being a regular old science writer, because I did not actually have to write anything. I thus got to recharge my depleted store of metaphors (my brain was a wasteland, a barren desert, a bachelor's refrigerator), rest my tendonitis-ridden mouse arm and leave verbs unconjugated. I declined all declensions.

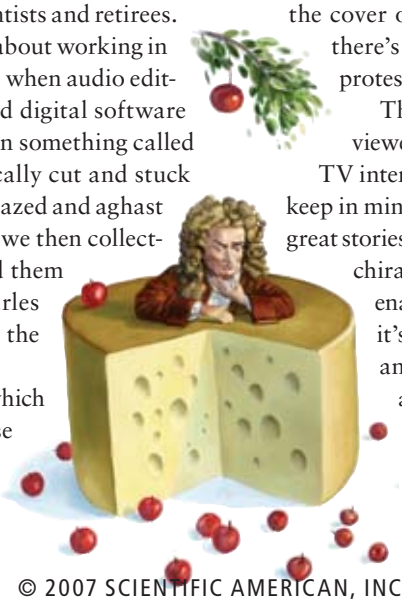
I also visited the Center for Dairy Research—this is Wisconsin, after all—where I had my inaugural mouthful of cheese curds, the first coagulated bits that form in the cheese-making process. As advertised, if they're superfresh, they will indeed squeak when you chew them, thanks to their still supple, rubbery band of proteins. A few hours past freshness and the cheese is as quiet as a mouse.

My time, of course, wasn't all cheese popping and not writing. I was not on some kind of scrivener's version of an agricultural subsidy, in which I would be rewarded for not growing alfalfa. In fact, while my mouse arm healed, my throat became ever sorer—I yapped incessantly. I interviewed various scientists about the secrets of their work and shared some secrets of my work with journalism students, newspaper people, scientists and retirees. This last group was delighted to hear stories about working in radio in the long-forgotten days of the 1980s, when audio editing was accomplished not with sophisticated digital software but with razor blades. Audio was recorded on something called "tape" back then, which we actually physically cut and stuck back together. The younger students were amazed and aghast at this factoid, so I went on to tell them that we then collected the leftover pieces of tape and assembled them into the single-engine tinderbox that Charles Lindbergh flew to become the first man on the moon in 1989.

Back to cheese, which goes with apples, which may be why just a short walk from the cheese research building is the Newton apple tree, which, a plaque notes, is "a direct descendant of the original tree said to have borne the fruit that inspired Sir Isaac Newton's Theory of Gravitational Forces." Thus was Newton able to describe the motion around Earth of the moon, regardless of what kind of cheese Lindbergh discovered it was made from.

Speaking of the moon, I also told some campus astronomers that *Scientific American* was attempting to be more accessible to more readers, because even professional scientists had complained to us that the articles outside their own fields had become too technical to follow. A professor emeritus of astronomy then told me that he indeed had heard that very complaint once voiced by a professional scientist—J. Robert Oppenheimer, who knew something about technical matters.

One of the more thought-provoking sessions of my week was with scientists interested in the journalist-interviewee process. I'm typically on *this* side of that equation, asking them. They wanted to know more about *that* side, being asked. Which might be of interest to anyone, because we live in a time when any of us can suddenly be thrown into a media spotlight—some men strive to be on the cover of *Time* magazine, some have the cover of *Time* thrust upon them. (Becoming suddenly famous is not necessarily a good thing—if you're just a regular person and you wind up on the cover of one of next week's national newsweeklies, there's a good chance that you're dead and there are protest marches about who was responsible.)



The most common question from potential interviewees was how to not be nervous for a live radio or TV interview. I nervously replied that the best thing to keep in mind is that you're indeed the guest. Sure, you have great stories about tweaking the Diels-Alder reaction with a chiral catalyst to produce polycyclic products in high enantiomeric excess. But you don't have to feel like it's your responsibility to keep the program light and bouncy—that's the host's job. So you can just answer the question, stop when you're done and wait for the host to jump back in to keep the conversation moving. It's like being on a blind date and you're the cute one. ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS

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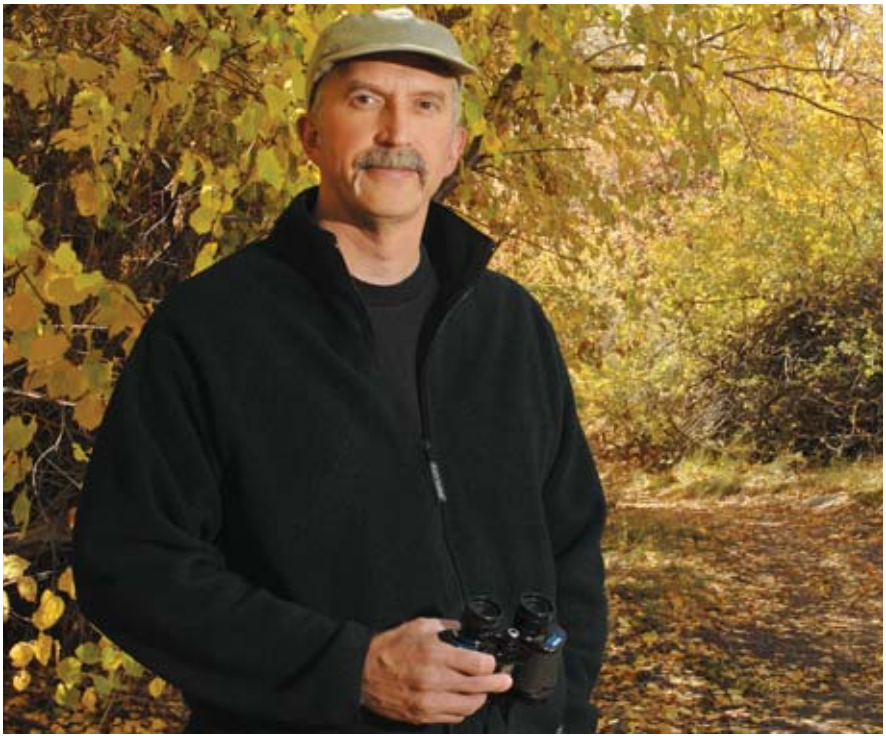
Bigfoot Anatomy

Sasquatch is just a legend, right? According to the evidence, maybe not, argues Jeffrey Meldrum—a position he holds despite ostracism from his fellow anthropologists and university colleagues BY MARGUERITE HOLLOWAY

One overcast Sunday morning in 1996, Jeffrey Meldrum and his brother drove to Walla Walla, Wash., to see if they could find Paul Freeman, a man renowned in Bigfoot circles as a source of footprint casts. Meldrum—who has followed Bigfoot lore since he was a boy—had heard that Freeman was a hoaxer, "so I was very dubious," he recalls. The brothers arrived unannounced, Meldrum says, and chatted with Freeman about his collection. Freeman said he had found tracks just that morning, but they were not good, not worth casting. The brothers wanted to see them regardless. "I thought we could use this to study the anatomy of a hoax," Meldrum says. Instead Meldrum's visit to a ridge in the Blue Mountains set him firmly on a quest he has been on since.



Meldrum, an associate professor of anatomy and anthropology at Idaho State University, is an expert on foot morphology and locomotion in monkeys, apes and hominids. He has studied the evolution of bipedalism and edited *From Biped to Strider* (Springer, 2004), a well-respected textbook. He brought his anatomical expertise to the site outside Walla Walla. The 14-inch-long prints Freeman showed him were interesting, Meldrum says, because some turned out at a 45-degree angle, suggesting that whatever made them had looked back over its shoulder. Some showed skin whorls, some were flat with distinct anatomical detail, others were of running feet—imprints of the front part of the foot only, of toes gripping the mud. Meldrum made casts and decided it would be hard to hoax the running footprints, "unless you had some device, some cable-loaded flexible toes."

To Meldrum, the anatomy captured in those prints and the casts of others he has examined as well as still unidentified hairs, recordings of strange calls and certain witness testimonials all add up to valid evidence that warrants study. He reviews that evidence in *Sasquatch: Legend Meets Science* (Forge, 2006). "My book is not an attempt to convince people of the existence of Sasquatch," the 49-year-old Meldrum says emphatically; rather it argues that "the evidence that exists fully justifies the investigation and the pursuit of this question."

To Meldrum's critics—including university colleagues and scientists in his own field—that same collection does not constitute valid evidence, and Meldrum's examination of it is pseudoscientific: belief shrouded in the language of scientific rigor and analysis. "Even if you have a million pieces of evidence, if all the evidence is inconclusive, you can't count it all up to make something conclusive," says David J. Daegling, an anthropologist at the University of Florida who has critiqued Meldrum and the Bigfoot quest in the *Skeptical Inquirer* and is the author

JEFFREY MELDRUM

BIG ON BIGFOOT: Respected for his primate and hominid anthropology work, he receives opprobrium for his investigations of the Sasquatch legend.

TOUGH SKIN: "If I didn't think there was some merit to this, I wouldn't endure the slings and arrows."

SUSAN DUNCAN

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of *Bigfoot Exposed* (AltaMira, 2004).

Neither side can win its case without a Sasquatch specimen or fossil or without the true confessions of a fleet of perhaps fleet-footed hoaxers. In the meantime, observers watch a debate that is striking in that both sides use virtually the same language, refute each other's interpretations with the same tone of disbelief and insist they have the identical goal: honoring the scientific method. And the question of how science on the fringe should be dealt with remains open: some observers say that Meldrum, who has been lambasted by colleagues and passed over for promotion twice, should just be left alone to do his thing; others counter that in this era of creationism, global warming denial, and widespread antiscience sentiment and scientific illiteracy, it is particularly imperative that bad science be soundly scrutinized and exposed.

Meldrum is a tall, mustached man, relaxed, friendly and gregarious. On a recent summer morning in his office—rich in Bigfoot paraphernalia—he explains that his interest in the subject arose when he was 11 and saw Roger Patterson's now famous film of an alleged Sasquatch loping into the forest. Meldrum listed cryptozoology (the study of hidden creatures such as yeti and Nessie) as an interest on his vitae when he applied for doctoral work. But Bigfoot as an active pursuit did not emerge until he arrived at Idaho State in 1993 and was back in the Pacific Northwest, where he grew up.

Meldrum's laboratory houses more than 200 casts relating to Bigfoot. As he pulls out drawers and talks about the casts, Meldrum shows ones with the hallmarks of hoax and others that intrigue him because of anatomy, hair striations, musculature and an apparent midtarsal break—a pair of joints in the middle of the ape foot that have less mobility in the human foot because of the arch. He brings out a particularly controversial piece called the Skookum cast that he thinks may be of a reclining Sasquatch and others think may be of a reclining elk. "There is a chance we are wrong," he says. "But with the footprints, I feel more certain." Discounting the unusual casts "isn't scientific in the least," Meldrum maintains, and "it is irresponsible."

"He does bring more scientific rigor to this question than anyone else in the past, and he does do state-of-the-art footprint analysis," notes David R. Begun, a paleoanthropologist at the University of Toronto. Todd R. Disotell, a New York University anthropologist, agrees: "He is trying to bring rigor to it." Both researchers collaborate with Meldrum even though they do not accept his hypothesis that a large apelike creature exists. "If he hands me a feces sample or a bloodstain or a hair shaft, I am willing to do what I do with anything I get," Disotell says. "I go along with this because I am either doing good science, finding alternatives or debunking, or I have the find of the century." Disotell gets Bigfoot jibes over beers sometimes, but nothing similar to what Meldrum experiences: "I think what is happening to him is a shame."

CASTS OF HUNDREDS: Jeffrey Meldrum's collection leads him to believe that a bigfooted biped may lurk in the forests of the Pacific Northwest.

PAUL HOSEFROS

In his famous "Cargo Cult Science" lecture in 1974, Richard Feynman described scientific thinking and integrity as "a kind of utter honesty—a kind of leaning over backwards" to raise and examine every doubt, every interpretation. This kind of thinking, critics say, is missing from Meldrum's Bigfoot work, whereas it infuses his fossil and primate gait research. Meldrum's principal critic from his own field is Daegling, who concludes that the "evidence doesn't look better on deeper analysis, it looks worse." He adds that "this isn't about Bigfoot—it is about how scientists go about doing their work and how we should be self-reflective and self-critical."

Meldrum responds by saying that most people do not see him critically sifting through all the evidence that comes his way—and discarding most of it. But if he is at times frustrated and beleaguered by skeptics, it appears some in his community are beleaguered by his exhortation that more researchers accept his interpretations or become involved. In reviewing Meldrum's and Daegling's books in the *American Journal of Physical Anthropology,* Matt Cartmill of Duke University concludes that if the chances of Bigfoot's being real are one in 10,000 (his admittedly wild guess), then having one physical anthropologist on the case seems a reasonable allocation of professional resources and that Meldrum does not deserve scorn or abuse. But Cartmill, who notes that he is "mortally certain" there is no Sasquatch, is irked by Meldrum's trying to guilt-trip those who do not do Bigfoot work and his disparaging them as lazy or aloof.

The tension is inevitable for science on the fringe, says Trent D. Stephens of Idaho State who co-authored a book with Meldrum on evolutionary biology and Mormonism. As he puts it: "The stuff that is on the margins, the stuff that isn't popular—we scientists are horrible at judging it. And we say our mistakes about the fringe are all historical; we claim we are not making those mistakes today."

The fringe has produced wonderful science, and it has produced wonderfully abysmal science. It has never been a comfortable place to live. ■

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Window on the Extreme Universe

The **GLAST** satellite is about to open up an unexplored region of the electromagnetic spectrum—just the region, in fact, where signs of dark matter and other mysterious phenomena may show up

KEY CONCEPTS

- The year 2008 marks the start of a new era in physics with the start-up of the Large Hadron Collider (LHC), one of the most eagerly anticipated instruments in the history of the physical sciences. But the LHC is not the only upcoming discovery machine. Another is the Gamma-ray Large Area Space Telescope (GLAST).
- GLAST brings two bottles of wine to the party: it covers an almost unexplored range of gamma-ray energy, and it can precisely measure the arrival time of gamma pulses. These capabilities allow GLAST to probe various proposals for extending the current Standard Model of particle physics.
- Working together, the LHC and GLAST may be able to identify the dark matter that accounts for the bulk of the material content of the universe.

—The Editors

By William B. Atwood, Peter F. Michelson and Steven Ritz

This coming spring scientists will open dramatic new views of the universe. NASA plans to launch the Gamma-ray Large Area Space Telescope (GLAST) to explore exotic environments such as those of supermassive black holes and neutron stars, which generate enormous power in high-energy gamma rays. Around the same time, the Large Hadron Collider (LHC) at CERN, the European laboratory for particle physics near Geneva, will begin providing an unparalleled view of nature's fundamental building blocks and their interactions at the smallest distances. GLAST may probe some of the same microscopic phenomena as the LHC does and show us how these processes work in their natural cosmic settings. Such exciting and revolutionary times in science are rare.

Gamma rays are electromagnetic radiation at the highest-energy, or shortest-wavelength, end of the electromagnetic spectrum. Vastly more energetic than optical light or even x-rays, gamma-ray photons each carry so much energy that it is possible to convert some of that energy into particles of matter, through processes that are implied by Albert Einstein's famous $E = mc^2$ relation.

Surprisingly rich and variable, the gamma-ray sky is very different from what we experience with our eyes. The seemingly placid night sky becomes a cauldron of supermassive black holes hurling matter into space at nearly the speed of light, massive stellar explosions and their shimmering aftermath, hyperdense neutron stars with gargantuan magnetic fields, and the high-energy glow of the galaxy from collisions of charged particles known as cosmic rays.

SLIM FILMS (*satellite and background sky*); J. DIEMAND, M. KUHLEN AND P. MADAU *University of California, Santa Cruz (simulated dark matter map)*

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Cosmic gamma rays might also come from the annihilation of the exotic particles that make up the mysterious dark matter. The LHC seeks to create those particles in the laboratory.

The possibility of gamma-ray astronomy was anticipated by the late physicist Philip Morrison (also a former *Scientific American* columnist) in a seminal 1958 paper. He noted that optical light, including starlight, is actually reprocessed emission that is only indirectly related to its original source, usually nuclear and subnuclear processes that occur at much higher energies. In fact, gamma-ray emission is much closer to the energy of the underlying astrophysical processes. It inherently identifies sites of extreme physical conditions and carries direct information about what occurs there.

Gamma rays usually have no trouble crossing most of the visible universe—billions of light-years—but they splatter on our atmosphere. In so doing, they convert their energy into showers of lower-energy particles. For the very highest energy gamma rays—above approximately 100 billion electron volts (GeV), to use particle physicists' standard energy units—the signal from the atmospheric particle shower is large enough to be picked up by specially designed ground-based observatories. But below this energy scale, researchers must launch special telescopes into space.

As with most astrophysical investigations, the wealth of gamma-ray emission in the universe cuts both ways: one investigator's signal is another's unwanted background. When hunt-

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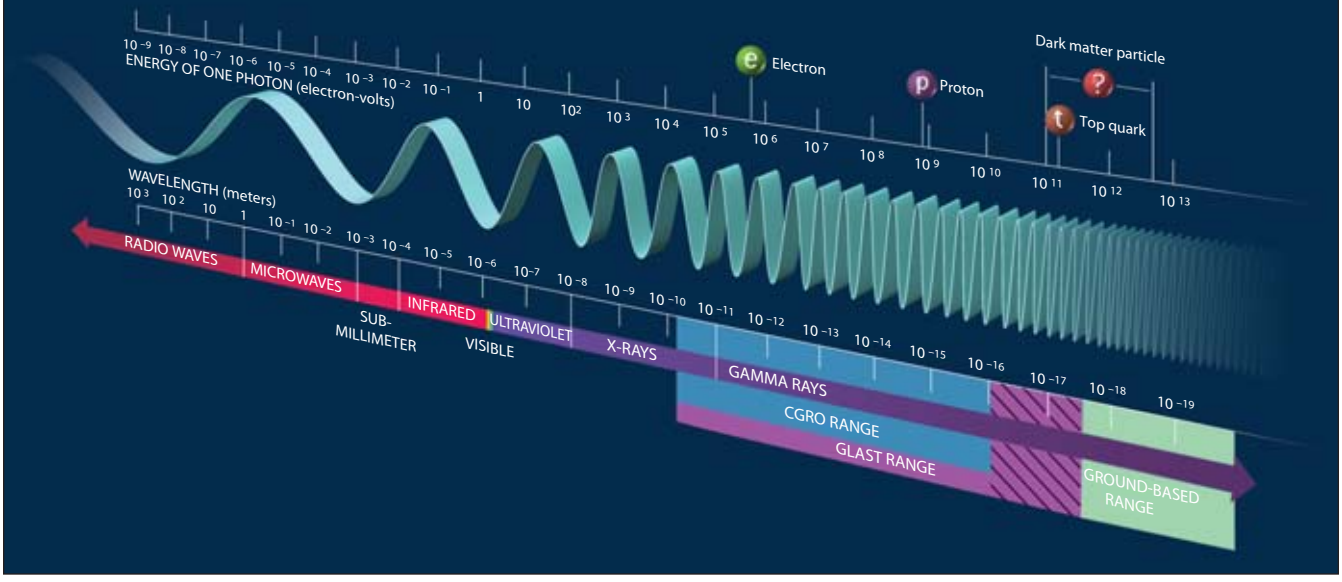
[THE ELECTROMAGNETIC SPECTRUM]

OPENING THE WINDOW

The GLAST satellite monitors a wide swath of the spectrum, including a hitherto unobserved region from 10 to 100 giga-electron-volts (*hatched*). Lying in this region could be the clues to mysteries such as the composition of dark matter.



ing for evidence of new phenomena, researchers must first exclude conventional astrophysical interpretations of the data. With this caveat, deep questions of physics can currently be answered only by astrophysical observations of the kind GLAST will soon provide.

From EGRET to GLAST

When it comes to studying the universe at high energies, the scientific questions and experimental techniques demand the expertise of both particle physicists and astronomers. The convergence of these traditionally distinct disciplines is one of the major trends in the physical sciences over the past two decades [see "When Fields Collide," by David Kaiser; SCIENTIFIC AMERICAN, June]. The three of us are evidence of that. Atwood and Ritz have backgrounds in particle physics, and Michelson is an astrophysicist and a member of the team that developed the Energetic Gamma Ray Experiment Telescope (EGRET), which flew on NASA's last major gamma-ray satellite, the Compton Gamma Ray Observatory (CGRO).

The primary instrument on GLAST, the Large Area Telescope, owes its origin to a seminar that Michelson gave at the Department of Energy's Stanford Linear Accelerator Center (SLAC) in 1991. During subsequent discussions that Michelson and Atwood had with members of SLAC's recently formed particle astrophysics group, led by Elliott Bloom, Atwood laid the groundwork for the LAT design. He proposed adapting silicon-based particle detectors, development of which was driven by the Superconducting Super Collider project, for use in gamma-ray telescopes. Although the collider project died, its technology lives on in GLAST. A second instrument on the GLAST observatory, the Burst Monitor, developed by a team led by Charles Meegan of the NASA Marshall Space Flight Center, monitors the sky for bursts of radiation in the energy band below that covered by the Large Area Telescope. The GLAST project draws on the expertise and effort of scientists, engineers and technicians in the U.S., France, Germany, Italy, Japan and Sweden.

Compared with EGRET, the Large Area Telescope will collect more than 100 times the number of gamma rays. Its field of view is comparable to that of the human eye, seeing approximately 20 percent of the sky at a time. In two orbits around Earth, taking about three hours, GLAST will cover the entire sky. This capability is particularly important for finding transient sources that were a feature of the gamma-ray sky observed by EGRET. In a matter of days, GLAST will achieve the same source sensitivity that EGRET took years to reach. The Large Area Telescope and the Burst Monitor together cover a factor of more than 10 million in energy across the electromagnetic spectrum.

FAST FACT

GLAST's main instrument, the Large Area Telescope, has a mass of three tons yet uses less than half the power of a hair dryer.

SLIM FILMS

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With such a large leap in capability, GLAST will bring important new insights into supermassive black holes and neutron stars, which generate enormous power in gamma rays. Consequently, it will vastly improve on the work of EGRET, which was unable to identify two thirds of the gamma sources it detected. The satellite may also find signatures of phenomena beyond the Standard Model of particle physics and provide tests of Standard Model processes in extreme settings. Here is a list of some of the exotic possibilities.

1 Dark Matter

Astronomers have known since the 1930s that there is more to the universe than meets the eye. Galaxies moving around within clusters of galaxies and stars moving around within galaxies are going faster than the gravity of the visible matter would imply, indicating that a huge amount of invisible matter is pulling on them. Physicists, meanwhile, have realized that extensions to the Standard Model may provide the answer to what this stuff is. The most popular of these extensions involves a hypothetical aspect of nature known as supersymmetry, looking for which is one of the top goals of the LHC [see "The Dawn of Physics beyond the Standard Model," by Gordon Kane; SCIENTIFIC AMERICAN, June 2003].

Supersymmetric dark matter particles are not truly dark. Although they may not interact with ordinary matter and light very much, they are thought to have the interesting property that they are their own antiparticles. So whenever two of these particles meet, they annihilate, converting their large masses to energetic particles—including gamma rays. The trick will be to distinguish this radiation from similar emission from other sources. So little is known about dark matter that estimates of the intensity and energy of its gamma output range hugely.

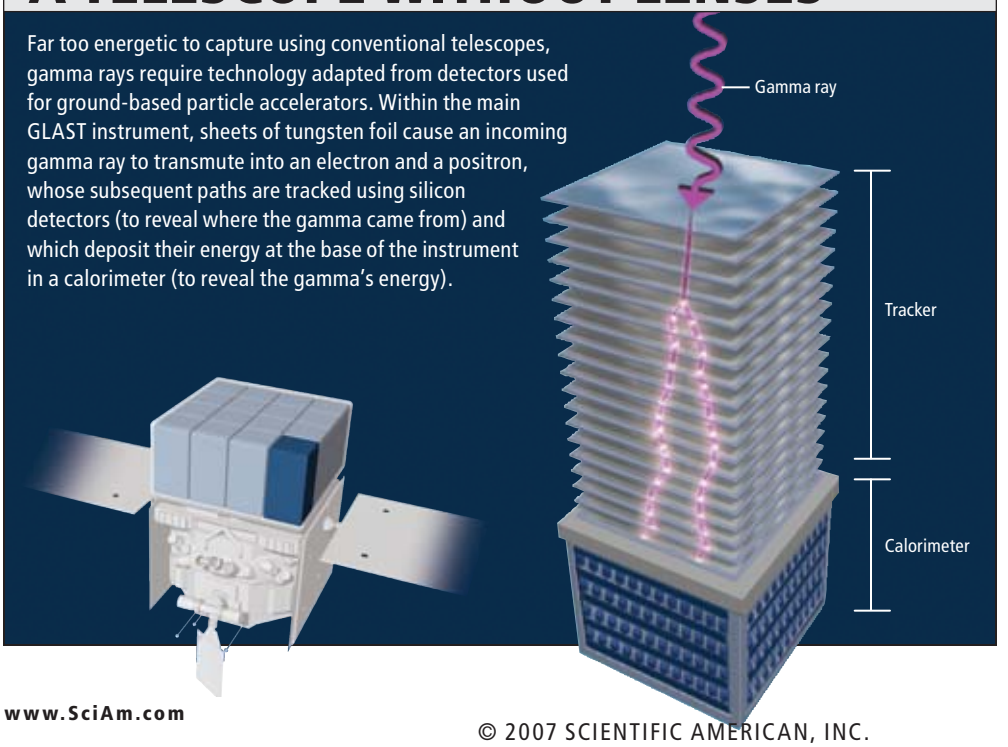
In the clearest-cut cases, the annihilation results in just two gamma-ray photons whose energy equals the mass of the dark matter particles, now thought to be around a few hundred GeV. This situation is the dark matter version of the distinctive 511 kilo-electron-volt (keV) gammas produced when electrons and their antimatter partners, positrons, annihilate. When astronomers see gammas of 511 keV, they know that positrons must be involved. Similarly, if astronomers see too many gammas with an energy in the 100-GeV range, they will know that dark matter must be involved.

Even though the interpretation of such a signal would be unambiguous, the chance it would be strong enough to observe is very small. Most of the energy released by dark matter annihilation would emerge over a broad range of energy. Unfortunately, this signal would sit on top of the much more abundant gamma radiation pro-

[GLAST'S LARGE AREA TELESCOPE]

A TELESCOPE WITHOUT LENSES

Far too energetic to capture using conventional telescopes, gamma rays require technology adapted from detectors used for ground-based particle accelerators. Within the main GLAST instrument, sheets of tungsten foil cause an incoming gamma ray to transmute into an electron and a positron, whose subsequent paths are tracked using silicon detectors (to reveal where the gamma came from) and which deposit their energy at the base of the instrument in a calorimeter (to reveal the gamma's energy).



NASA (*authors*); SLIM FILMS (*illustration*)

[THE AUTHORS]

William B. Atwood, Peter F. Michelson and Steven Ritz are part of the large international team of scientists, engineers and technicians that made GLAST a reality. Atwood, currently an adjunct professor at the University of California, Santa Cruz, has worked on numerous particle physics experiments, including the SLAC experiment credited for having discovered quarks. He is also a noted violin-maker with more than 50 instruments bearing his label. Michelson is a professor at Stanford University and the principal investigator for the GLAST Large Area Telescope. He began his scientific career studying superconductivity and turned his interest to astrophysics after developing instrumentation for gravitational-wave detection. Ritz, an astrophysicist at the NASA Goddard Space Flight Center and adjunct professor at the University of Maryland, is the GLAST project scientist. He is also a music composer.

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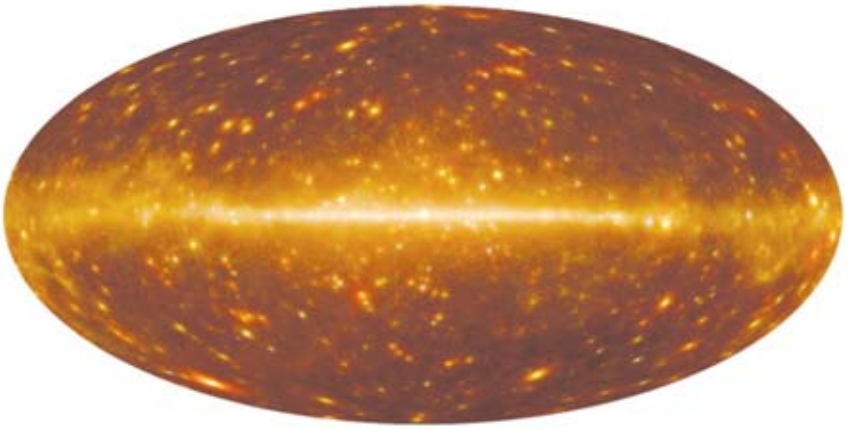

IF YOU HAD GAMMA-RAY VISION, here is what you might see, based on a simulation of the GLAST satellite's capability. The image is a projection of sky centered on the core of our Milky Way galaxy. The bright horizontal band shows the galaxy's disk aglow in gamma radiation, mainly representing cosmic rays slamming into interstellar gas molecules. Most of the thousands of bright points are supermassive black holes in the cores of faraway galaxies. In addition to these features, signals of new physics may appear.

duced as cosmic rays collide with interstellar gas and radiation fields. In this case, seeing the dark matter signal would be like straining to see stars in the glare of city lights. Fortunately, gammas from dark matter should have a different spectrum and populate the sky in a distinctive pattern. For instance, they should clump near the center of galaxies. That bias will aid in their detection.

GLAST's data will mesh neatly with those of contemporaneous particle physics measurements. The LHC may produce new particles, measure their mass and determine how strongly they interact with other particles. These particles will be candidates for dark matter. GLAST can then determine the role these newly found particles play in the universe at large. Any such particles will escape from the accelerator too quickly for physicists to find out whether they are stable, so GLAST's data will be essential for determining whether the particles can live long enough to serve as dark matter. GLAST will also dovetail with efforts to detect the dark matter directly as it streams through our planet [see "The Search for Dark Matter," by David B. Cline; Scientific American, March 2003].

2 Mini Black Holes

Special relativity and quantum mechanics, the theoretical pillars of modern physics, have been connected in profound ways, but incorporating general relativity—and therefore the force of gravity—remains a work in progress. A remarkable prediction emerged in the 1970s, when Stephen Hawking of the University of Cambridge and his colleagues reasoned that the combination of gravity with quantum fluctuations in energy would imply that black holes are unstable. These bodies should radiate particles, the energy of which would increase as the hole shrinks, leading to a runaway reaction and eventually a dramatic explosion [see "Quantum Black Holes," by Bernard J. Carr and Steven B. Giddings; Scientific American, May 2005].

This process is too slow to affect large black holes noticeably, but if conditions were right in the early universe to make black holes, some might be small enough to be blowing up today. Although the very smallest ones would have already evaporated, those with a mass of about 10^{12} kilograms—equivalent to a small asteroid—would last about 14 billion years. Thus, if such little black holes were produced (and it is fair to say that many of our theorist colleagues are skeptical), GLAST has an opportunity to observe a process that profoundly connects quantum mechanics and gravity.

3 Extra Dimensions of Space

Efforts to develop such theories have led some physicists to postulate that our three-dimensional universe is embedded in a space with additional dimensions. In certain versions of these theories, we do not see the extra dimensions because matter and nongravitational forces such as electromagnetism are confined to our three-dimensional volume. Gravity, though, faces no such restriction. The graviton particles that transmit gravity can have cousins, called Kaluza-Klein gravitons, that propagate throughout a higher-dimensional volume.

If those dimensions are sufficiently large in size, they would change the behavior of gravity in ways that GLAST (and perhaps also the LHC) could pick up [see "The Universe's Unseen Dimensions," by Nima Arkani-Hamed, Savas Dimopoulos and Georgi Dvali; Scientific American, August 2000]. For example, supernova explosions could pump some of their energy into these exotic gravitons, which would in turn decay to other particles, notably gamma rays. EGRET looked for such effects and saw none, leading physicists to conclude that no more than about 1 percent of the supernova energy could wind up in Kaluza-Klein gravitons. GLAST will see many more such objects with much greater sensitivity and, at the very least, will rule out versions of these extra-dimensional theories.

GLAST-LAT SPECS

9,500 cm^2
Effective collecting area of telescope

20% of the sky
Field of view

20 MeV to 300 GeV
Energy range

10 μsec
Time resolution

30 million
Number of photons observed per year

LAT TEAM/NASA

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4 Violations of Special Relativity

A cornerstone of special relativity is that the speed of light in a vacuum is independent of wavelength. High-energy (short-wavelength) and low-energy (long-wavelength) photons should all travel at the same speed. This constancy is a manifestation of a deep principle called Lorentz invariance, the mathematical embodiment of Einstein's principle that the laws of physics are the same for all observers moving at a constant velocity.

But does this principle really hold? In a quantum theory of gravity, it might not. The fine-scale shape of spacetime may fluctuate, and high-energy photons would be more sensitive to these perturbations than lower-energy ones. By analogy, a baby stroller with small wheels is more sensitive to the shape of the pavement than a Mack truck with large tires. As the high-energy photons navigate the perturbations, they might have to travel a comparatively longer or shorter distance, lengthening or shortening their journey across the universe [see "The Search for Relativity Violations," by Alan Kostelecký; Scientific American, September 2004]. The best way to measure very small differences in speed is to hold a very long race: the longer the race, the bigger the difference in arrival times at the finish line. Nature conducts just such a race every time a gamma-ray burst goes off. The burst unleashes pulses of photons of various energies, which can travel billions of light-years to reach us.

EGRET detected only six bursts within its field of view and only a handful of photons for each. GLAST will surely pick up many more. It will be able to search for time differences in the arrival of high- and low-energy gamma rays from bursts at a range of distances from us. Some models predict differences of 10 milliseconds or more, resolvable by GLAST. If the satellite detects a difference, physicists will first have to exclude more conventional astrophysical explanations, such as effects within the bursting stars themselves. One test will be whether the time difference increases steadily with cosmic distance; if it does, it will cast doubt on most conventional explanations. Another test will be whether the same time difference occurs for gamma rays from objects of various types, not just gamma-ray bursts but also flares generated by supermassive black holes.

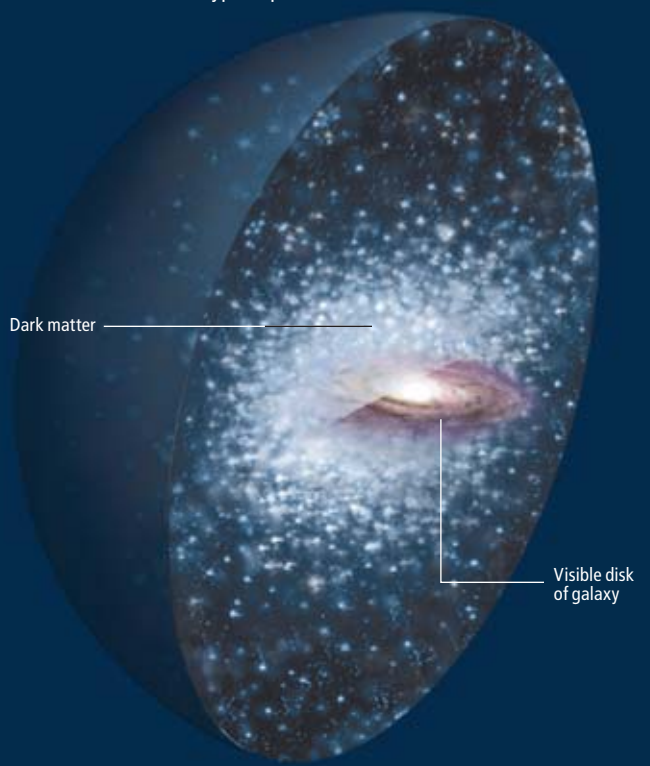
FAST FACT

If GLAST were a piano, it would cover 23 octaves. The two GLAST instruments cover more than seven orders of magnitude in energy.

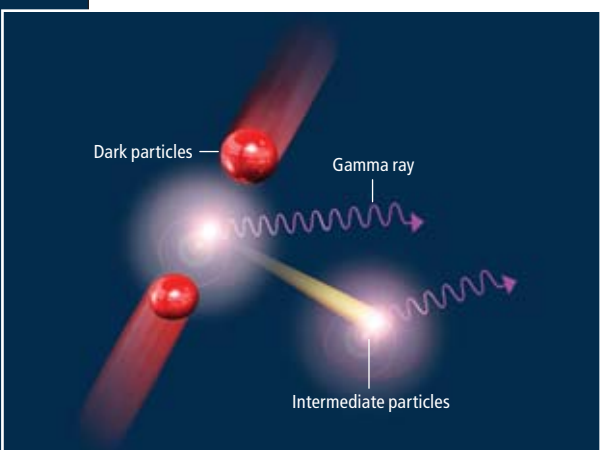
[EXOTIC PARTICLES]

WHAT'S THE MATTER?

PROBLEM: The galaxy is heavier than astronomers can account for. Does the "missing mass" consist of an exotic type of particle?



IMPLICATIONS: If GLAST sees these gamma rays, it would not only confirm that particle dark matter indeed exists (thereby ruling out alternative theories), it would reveal some of the particle's properties, such as its mass and interactivity, giving physicists a fighting chance of explaining it.



OBSERVATIONS: Theory suggests that the dark particle is not strictly dark. If it encounters another particle of its kind, the two annihilate, which could produce a gamma ray of a telltale energy directly or might produce other particles, which in turn decay into gamma rays with a range of energies.

LOGAN PARSONS (*galaxy*); SLIM FILMS (*inset*)

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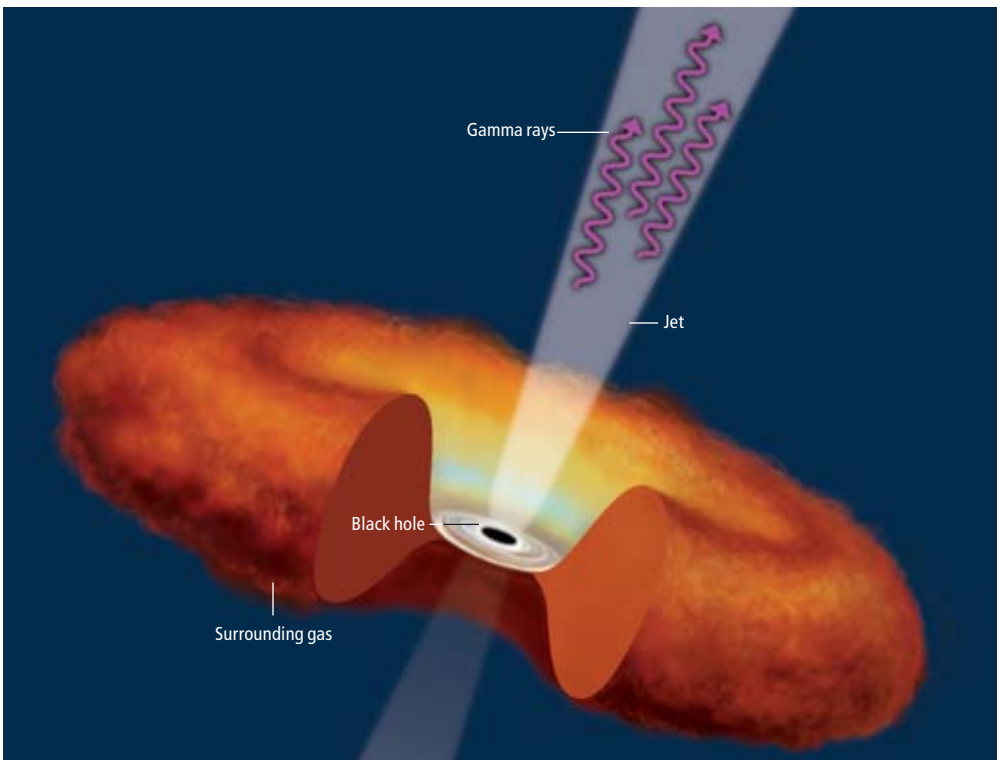
5 Matter under Extreme Conditions

The above phenomena would require new laws of physics to understand. But scientists struggle even to apply the laws we already have, and here GLAST will also be of major importance. For example, supermassive black holes appear to be common at the centers of galaxies and are deeply connected to the birth and development of their host galaxies. As the black hole at the center of a galaxy grows by accreting surrounding gas, the nucleus of the galaxy can ignite, becoming an active galactic nucleus (AGN). AGNs are one of the main sources of gamma rays in the universe.

These black holes do not give off gamma radiation directly. Instead they trigger powerful jets of energetic particles moving at close to the speed of light, which then collide with lower-energy photons and boost those photons to gamma-ray energies. Astrophysicists think the jets emerge along the spin axis of a rotating black hole and are powered by extracting the hole's rotational energy. The energy output in gamma rays alone can be as much as the energy output of all the stars in our galaxy across the entire electromagnetic spectrum.

The emerging gamma rays, therefore, provide a unique diagnostic for the extreme conditions near the hole. How do these jets remain so tightly collimated for thousands of light-years? Where and how is the kinetic energy of the jet converted into gamma radiation? GLAST, working with radio and optical observatories, may finally provide some answers by watching the spectra of these powerful sources evolve over time.

Rapidly spinning neutron stars are only one notch down from black holes on the scale of exotic cosmic objects. The magnetic fields of some of these objects are among the strongest known in nature, and they are the heart of systems that can accelerate charged particles to energies far in excess of what the LHC can manage [see "Magnetars," by Chryssa Kouveliotou, Robert C. Duncan and Christopher Thompson; Scientific American, February 2003]. Unusual particle reactions can take place near the surface of these objects, and gamma rays provide the best way to probe them. CGRO detected gamma radiation from



SUPERMASSIVE BLACK HOLES such as this one will be the most common extragalactic sources of gamma rays seen by GLAST. Compared with our solar system, the black hole is bigger than the orbit of Mars, and the surrounding disk of matter extends as far as the nearest star. Jets of high-speed material produce gamma rays in profusion. Studying them could help researchers understand the behavior of matter under some of the most extreme conditions imaginable.

JEN CHRISTIANSEN

FAST FACT

Dark matter isn't just "out there." Even in the space around us, astrophysicists believe it makes up the equivalent of one proton every three cubic centimeters.

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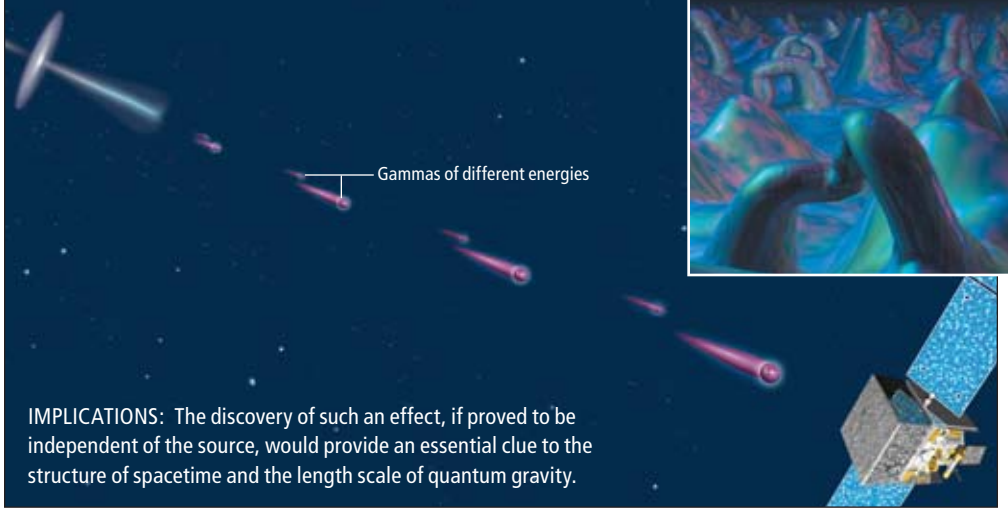
[TESTS OF RELATIVITY THEORY]

IS SPACETIME FOAMY?

PROBLEM: Einstein's general theory of relativity treats spacetime as a continuum. Could spacetime on closer examination really be a burbling froth, as some versions of quantum gravity theory suggest?



OBSERVATIONS: High-energy, short-wavelength gamma rays might feel such a foam (*below*) more strongly than lower-energy ones. The effect is necessarily very small but might result in a discernible difference in the time it takes a gamma ray to cross the universe (*at left*).

IMPLICATIONS: The discovery of such an effect, if proved to be independent of the source, would provide an essential clue to the structure of spacetime and the length scale of quantum gravity.

six young neutron stars in the Milky Way galaxy. Based on the best current theoretical models, we expect that GLAST will detect perhaps 10 times as many or more.

One of the biggest mysteries in astrophysics in the past several decades is the nature of gamma-ray bursts, very short flashes of high-energy radiation that come from random directions on the sky and appear only once, never to be seen again [see "The Brightest Explosions in the Universe," by Neil Gehrels, Luigi Piro and Peter J. T. Leonard; Scientific American, December 2002]. In recent years astronomers have made enormous progress in unveiling the sources of these cosmic explosions. They appear to arise either during births of black holes in the cores of dying massive stars or from the coalescence of binary neutron stars or black holes. In fact, both mechanisms may operate for different classes of bursts. GLAST is uniquely suited to solving these mysteries.

An extraordinary thing happens at high energies: light can interact with light. At low energies, two light beams pass right through each other without noticing, but at high energies, quantum effects make them more communicative. For example, as gamma rays pass through space, they can interact with starlight and produce electron-positron pairs. The optical photons thereby act as a haze through which gammas must pass, making the universe opaque to very high energy gamma rays from sources at large distances. GLAST can measure or constrain how much optical and ultraviolet light must fill space by measuring the gamma spectrum from a large number of active galaxies. From the amount of light, in turn, it can pin down how the rate of star formation has varied over cosmic time [see "The Cosmic Reality Check," by Günther Hasinger and Roberto Gilli; Scientific American, March 2002].

6 The Unexpected

Historically, large leaps in measurement capability have often revealed unanticipated features of nature. For instance, CGRO observed a very odd phenomenon in 1994. Seventy-five minutes after the onset of a gamma-ray burst, the satellite detected a lone gamma photon with a whopping energy of 18 GeV, the most energetic gamma ever seen from a burst. Theorists have speculated ever since about what this event says about the physics of bursts.

Who knows what the coming era of discovery will bring? Based only on the extrapolation from previous generations of space-based gamma-ray observatories, GLAST will surely resolve many of today's pressing questions about the high-energy universe, but no one knows what else will be seen through the window it opens. ■

MORE TO EXPLORE

The Edge of Infinity: Supermassive Black Holes in the Universe. Fulvio Melia. Cambridge University Press, 2003.

Very High Energy Gamma-Ray Astronomy. Trevor C. Weekes. Taylor and Francis, 2003.

Dark Cosmos: In Search of Our Universe's Missing Mass and Energy. Dan Hooper. HarperCollins, 2006.

The First GLAST Symposium Proceedings. Edited by Steven Ritz, Peter Michelson and Charles A. Meegan. AIP Conference Proceedings, Vol. 921; August 2007.

More information about GLAST can be found at the mission Web site: **www.nasa.gov/glast**

SLIM FILMS (*spacetime background*); ALFRED T. KAMAJIAN (*inset*)

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Are ALIENS among Us?

In pursuit of evidence that life arose on Earth more than once, scientists are searching for microbes that are radically different from all known organisms

By Paul Davies

ALIEN MICROBES may be hiding in plain sight. Although they might look like ordinary bacteria, their biochemistry could involve exotic amino acids or different elemental building blocks.

KENN BROWN *Mondolithic Studios*

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The origin of life is one of the great unsolved problems of science. Nobody knows how, where or when life originated. About all that is known for certain is that microbial life had established itself on Earth by about three and a half billion years ago. In the absence of hard evidence of what came before, there is plenty of scope for disagreement.

Thirty years ago the prevailing view among biologists was that life resulted from a chemical fluke so improbable it would be unlikely to have happened twice in the observable universe. That conservative position was exemplified by Nobel Prize–winning French biologist Jacques Monod, who wrote in 1970: "Man at last knows that he is alone in the unfeeling immensity of the universe, out of which he emerged only by chance." In recent years, however, the mood has shifted dramatically. In 1995 renowned Belgian biochemist Christian de Duve called life "a cosmic imperative" and declared "it is almost bound to arise" on any Earth-like planet. De Duve's statement reinforced the belief among astrobiologists that the universe is teeming with life. Dubbed biological determinism by Robert Shapiro of New York University, this theory is sometimes expressed by saying that "life is written into the laws of nature."

How can scientists determine which view is correct? The most direct way is to seek evidence for life on another planet, such as Mars. If life originated from scratch on two planets in a single solar system, it would decisively confirm the hypothesis of biological determinism. Unfortunately, it may be a long time before missions to the Red Planet are sophisticated enough to hunt for Martian life-forms and, if they indeed exist, to study such extraterrestrial biota in detail.

An easier test of biological determinism may be possible, however. No planet is more Earth-like than Earth itself, so if life does emerge readily under terrestrial conditions, then perhaps it formed many times on our home planet. To pursue this tantalizing possibility, scientists have begun searching deserts, lakes and caverns for evidence of "alien" life-forms—organisms that would differ fundamentally from all known living creatures because they arose independently. Most likely, such organisms would be microscopic, so researchers are devising tests to identify exotic microbes that could be living among us.

Scientists have yet to reach a consensus on a strict definition of life, but most would agree that two of its hallmarks are an ability to metabolize (to draw nutrients from the environment, convert those nutrients into energy and excrete waste products) and an ability to reproduce. The orthodox view of biogenesis holds that if life on Earth originated more than once, one form would have swiftly predominated and eliminated all the others. This extermination might have happened, for example, if one form quickly appropriated all the available resources or "ganged up" on a weaker form of life by swapping successful genes exclusively with its own kind. But this argument is weak. Bacteria and archaea, two very different types of microorganisms that descended from a common ancestor more than three billion years ago, have peacefully coexisted ever since, without one eliminating the other. Moreover, alternative forms of life might not have directly competed with known organisms, either because the aliens occupied extreme environments where familiar microbes could not survive or because the two forms of life required different resources.

The Argument for Aliens

Even if alternative life does not exist now, it might have flourished in the distant past before dying out for some reason. In that case, scientists might still be able to find markers of their extinct biology in the geologic record. If alternative life had a distinctively different metabolism, say, it might have altered rocks or created mineral deposits in a way that cannot be explained by the activities of known organisms. Biomarkers in the form of distinctive organic molecules that could not have been created by familiar life might even be hiding in ancient microfossils, such as those found in rocks dating from the Archean era (more than 2.5 billion years ago).

A more exciting but also more speculative possibility is that alternative life-forms have survived and are still present in the environment, constituting a kind of shadow biosphere, a term coined by Carol Cleland and Shelley Copley of the University of Colorado at Boulder. At first this idea might seem preposterous; if alien organisms thrived right under our noses (or even in our noses), would not scientists have discovered them already? It turns out that the answer is no. The vast majority of organisms are microbes, and it is almost impossible to tell what they are simply by looking at them through a microscope. Microbiologists must analyze the genetic sequences of an organism to determine

KEY CONCEPTS

- If, as many scientists believe, life can readily emerge under the right environmental conditions, it is possible that life arose on Earth more than once. Researchers are now seeking evidence of a second genesis by searching for exotic microbes that are biochemically different from all known organisms.
- Some of the best places to look for alternative life-forms are ecologically isolated niches such as ocean-bottom volcanic vents and the dry valleys of Antarctica.
- Alien microbes may also lurk right under our noses. Scientists can hunt for these organisms by looking for the markers of alternative biochemistry.

—The Editors

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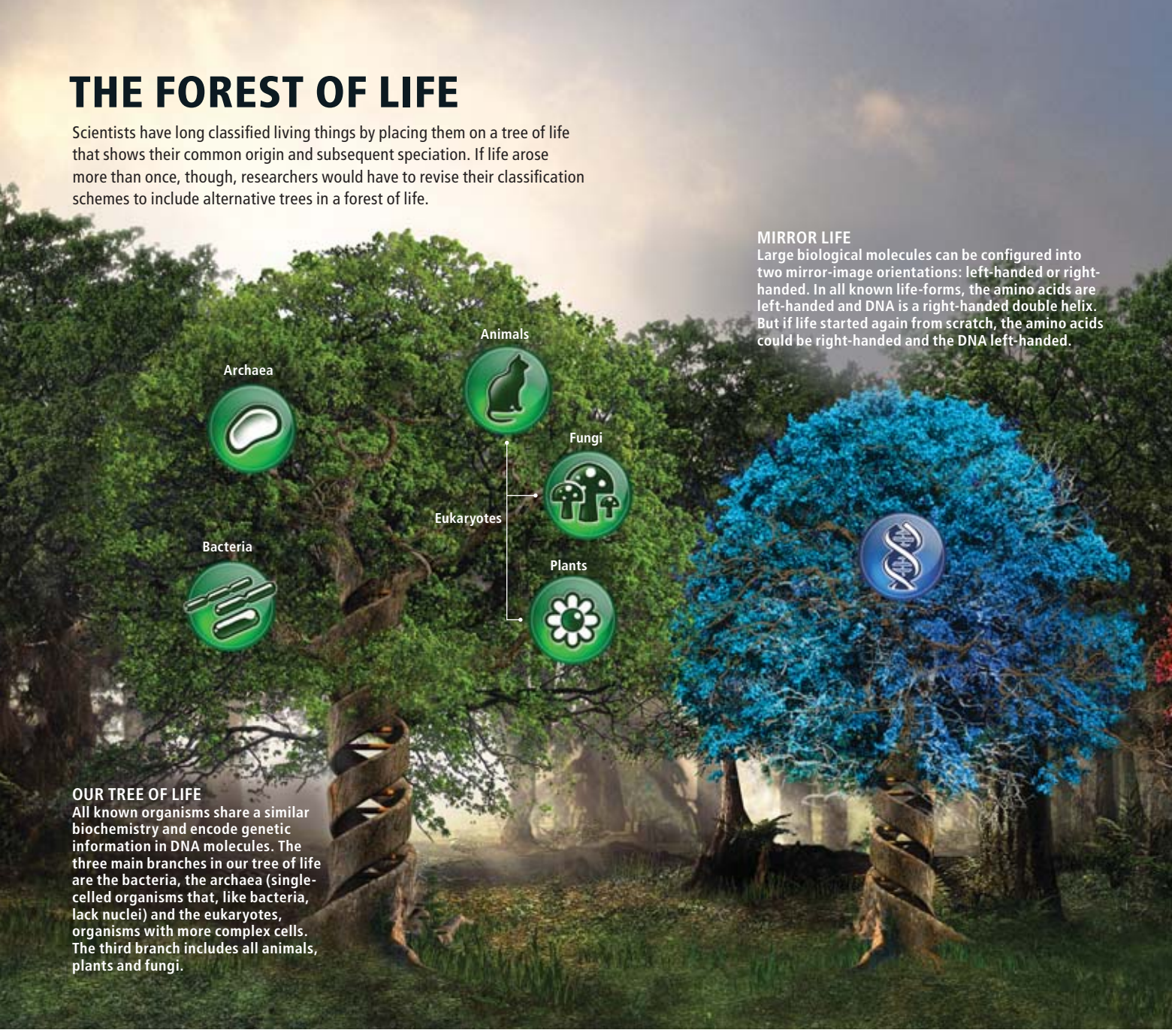
THE FOREST OF LIFE

Scientists have long classified living things by placing them on a tree of life that shows their common origin and subsequent speciation. If life arose more than once, though, researchers would have to revise their classification schemes to include alternative trees in a forest of life.



MIRROR LIFE
Large biological molecules can be configured into two mirror-image orientations: left-handed or right-handed. In all known life-forms, the amino acids are left-handed and DNA is a right-handed double helix. But if life started again from scratch, the amino acids could be right-handed and the DNA left-handed.

OUR TREE OF LIFE
All known organisms share a similar biochemistry and encode genetic information in DNA molecules. The three main branches in our tree of life are the bacteria, the archaea (single-celled organisms that, like bacteria, lack nuclei) and the eukaryotes, organisms with more complex cells. The third branch includes all animals, plants and fungi.

WHAT IS LIFE?

Most scientists would agree that the primary hallmarks of life are the following abilities:

- To draw nutrients from the environment
- To convert those nutrients into energy
- To excrete waste products
- To reproduce

its location on the tree of life—the phylogenetic grouping of all known creatures—and researchers have classified only a tiny fraction of all observed microbes.

To be sure, all the organisms that have so far been studied in detail almost certainly descended from a common origin. Known organisms share a similar biochemistry and use an almost identical genetic code, which is why biologists can sequence their genes and position them on a single tree. But the procedures that researchers use to analyze newly discovered organisms are deliberately customized to detect life as we know it. These techniques would fail to respond correctly to a different biochemistry. If shadow life is confined to the microbial realm, it is entirely possible that scientists have overlooked it.

Ecologically Isolated Aliens

Where might investigators look for alien organisms on Earth today? Some scientists have focused on searching for organisms occupying a niche that is ecologically isolated, lying beyond the reach of ordinary known life. One of the surprising discoveries in recent years is the ability of known life to endure extraordinarily harsh conditions. Microbes have been found inhabiting extreme environments ranging from scalding volcanic vents to the dry valleys of Antarctica. Other so-called extremophiles can survive in salt-saturated lakes, highly acidic mine tailings contaminated with metals, and the waste pools of nuclear reactors.

Nevertheless, even the hardiest microorganisms have their limits. Life as we know it de-

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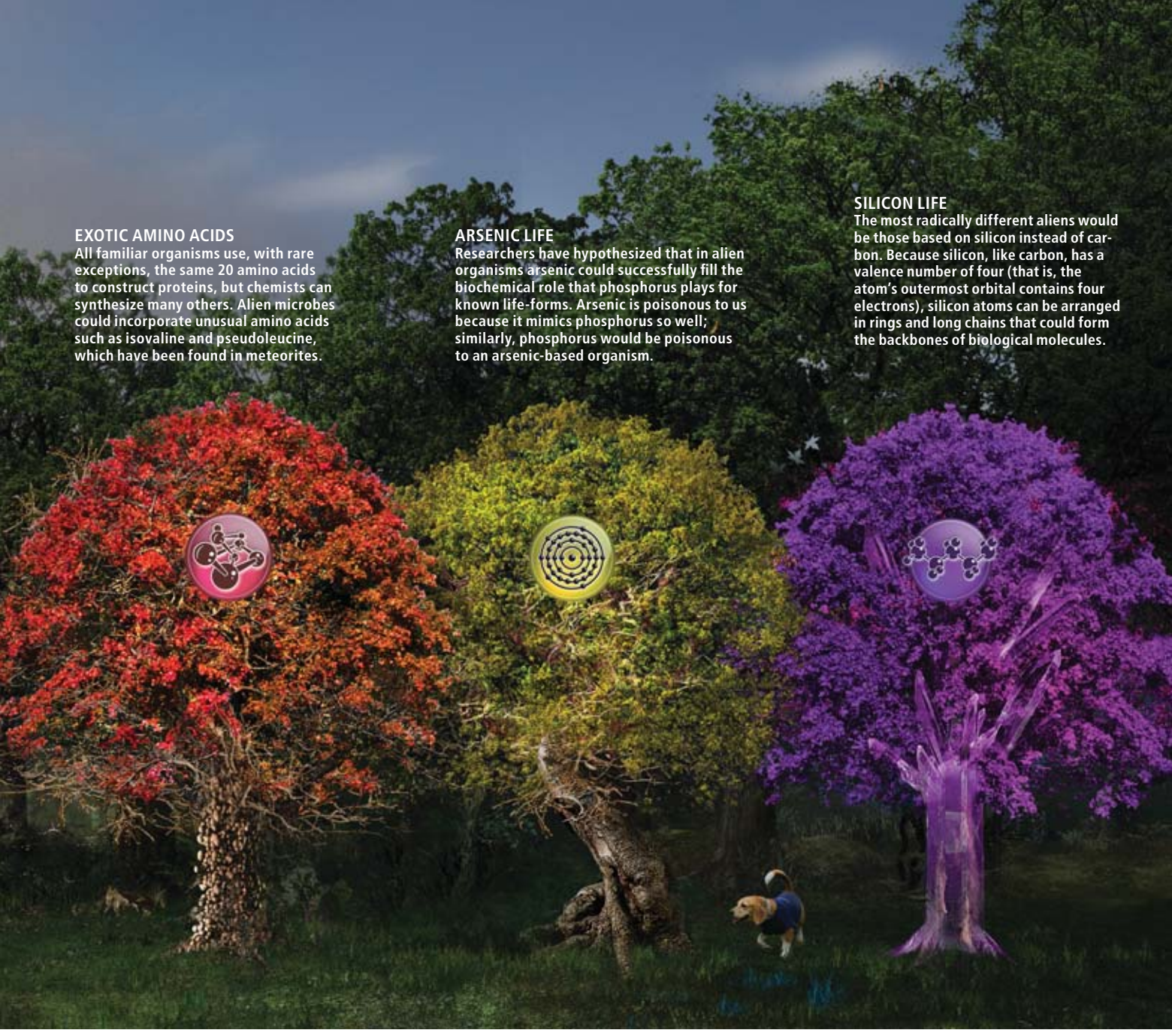

pends crucially on the availability of liquid water. In the Atacama Desert in northern Chile is a region that is so dry that all traces of familiar life are absent. Furthermore, although certain microbes can thrive in temperatures above the normal boiling point of water, scientists have not yet found anything living above about 130 degrees Celsius (266 degrees Fahrenheit). It is conceivable, though, that an exotic alternative form of life could exist under more extreme conditions of dryness or temperature.

Thus, scientists might find evidence for alternative life by discovering signs of biological activity, such as the cycling of carbon between the ground and the atmosphere, in an ecologically isolated region. The obvious places to look for such disconnected ecosystems are in the deep subsurface of Earth's crust, in the upper atmosphere, in Antarctica, in salt mines, and in sites contaminated by metals and other pollutants. Alternatively, researchers could vary parameters such as temperature and moisture in a laboratory experiment until all known forms of life are extinguished; if some biological activity persists, it could be a sign of shadow life at work. Scientists used this technique to discover the radiation-resistant bacterium *Deinococcus radiodurans*, which can withstand gamma-ray doses that are 1,000 times as great as what would be lethal for humans. It turns out that *D. radiodurans* and all the other so-called radiophiles that researchers have identified are genetically linked to known life, so they are not candidate aliens, but that finding does not rule out the possibility of

DOES LIFE REQUIRE WATER?

Researchers have long assumed that life could not arise without the presence of liquid water, but some astrobiologists have speculated that other liquids could serve as the solvent for biochemical reactions. Two alternatives are ethane and methane, which are liquid in very cold places such as the surface of Titan, Saturn's largest moon.

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Where to Look for Aliens

In the search for alternative microbes, some scientists have focused on ecologically isolated niches with harsh conditions that most ordinary organisms could not withstand. These niches include extremely alkaline and salty bodies of water such as Mono Lake in California (*left*), the dry valleys of Antarctica (*top right*), and polluted rivers such as Spain's Rio Tinto (*bottom right*), which is contaminated with heavy metals.

P. FRISCHKNECHT *Peter Arnold, Inc. (Mono Lake)*; MARIA STENZEL *National Geographic Image Collection (Antarctica)*; ERIC AND DAVID HOSKING *Corbis (Rio Tinto)*

discovering alternative life-forms in this way.

Investigators have already pinpointed a handful of ecosystems that appear to be almost completely isolated from the rest of the biosphere. Located far underground, these microbial communities are cut off from light, oxygen and the organic products of other organisms. They are sustained by the ability of some microbes to use carbon dioxide and hydrogen released by chemical reactions or radioactivity to metabolize, grow and replicate. Although all the organisms found to date in these ecosystems are closely related to surface-dwelling microbes, the biological exploration of Earth's deep subsurface is still in its infancy, and many surprises may lie in store. The Integrated Ocean Drilling Program has been sampling rocks from the seabed to a depth approaching one kilometer, in part to explore their microbial content. Boreholes on land have revealed signs of biological activity from even deeper locations. So far, however, the research community has not conducted a systematic, large-scale program to probe the deep subsurface of Earth's crust for life.

Ecologically Integrated Aliens

One might suppose it would be easier to find alternative life-forms if they were not isolated but integrated into the known biosphere existing all around us. But if shadow life is restricted to alien microbes that are intermingled with familiar kinds, the exotic creatures would be very hard to spot on casual inspection. Microbial morphology is limited—most microorganisms are just little spheres or rods. Aliens might stand out biochemically, though. One way to search for them is to make a guess as to what alternative chemistry might be involved and then look for its distinctive signature.

A simple example involves chirality. Large biological molecules possess a definite handedness: although the atoms in a molecule can be configured into two mirror-image orientations—left-handed or right-handed—molecules

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must possess compatible chirality to assemble into more complex structures. In known life-forms, the amino acids—the building blocks of proteins—are left-handed, whereas the sugars are right-handed and DNA is a right-handed double helix. The laws of chemistry, however, are blind to left and right, so if life started again from scratch, there would be a 50–50 chance that its building blocks would be molecules of the opposite handedness. Shadow life could in principle be biochemically almost identical to known life but made of mirror-image molecules. Such mirror life would not compete directly with known life, nor could the two forms swap genes, because the relevant molecules would not be interchangeable.

Fortunately, researchers could identify mirror life using a very simple procedure. They could prepare a nutrient broth consisting entirely of the mirror images of the molecules usually included in a standard culture medium; a mirror organism might be able to consume the concoction with gusto, whereas a known life-form would find it unpalatable. Richard Hoover and Elena Pikuta of the NASA Marshall Space Flight Center recently performed a pilot experiment of this kind, putting a variety of newly discovered extremophiles into a mirror broth and then looking for biological activity. They found one microbe that grew in the broth, an organism dubbed *Anaerovirgula multivorans* that had been isolated from the sediments of an alkaline lake in California. Disappointingly, this organism did not turn out to be an example of mirror life; rather it was a bacterium with the surprising ability to chemically alter the amino acids and sugars of the wrong handedness so as to make them digestible. The study, however, looked at just a small fraction of the microbial realm.

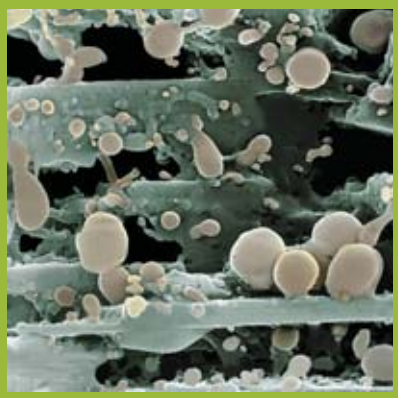
Another possibility is that shadow life might share the same general biochemistry with familiar life but employ a different suite of amino acids or nucleotides (the building blocks of DNA). All known organisms use the same set of nucleotides—designated A, C, G and T for their distinguishing bases (adenine, cytosine, guanine and thymine)—to store information and, with rare exceptions, the same 20 amino acids to construct proteins, the workhorses of cells. The genetic code is based on triplets of nucleotides, with different triplets spelling out the names of different amino acids. The sequence of triplets in a gene dictates the sequence of amino acids that must be strung together to build a particular protein. But chemists can synthesize many other amino acids that are not present in known organisms. The Murchison meteorite, a cometary remnant that fell in Australia in 1969, contained many common amino acids but also some unusual ones, such as isovaline and pseudoleucine. (Scientists are not sure how the amino acids formed in the meteorite, but most researchers believe that the chemicals were not produced by biological activity.) Some of these unfamiliar amino acids might make suitable building blocks for alternative forms of life. To hunt for such aliens, investigators would need to identify an amino acid that is not used by any known organisms nor generated as a by-product of an organism's metabolism or decay, and to look for its presence in the environment, either among living microbes or in the organic detritus that might be generated by a shadow biosphere.

To help focus the search, scientists can glean clues from the burgeoning field of synthetic, or artificial, life. Biochemists are currently attempting to engineer completely novel organisms by inserting additional amino acids into proteins. A pioneer of this research, Steve Benner of the Foundation for Applied Molecular Evolution in Gainesville, Fla., has pointed out that a class of molecules known as alpha-methyl amino acids look promising for artificial life because they can fold properly. These molecules, however, have not been found in any natural organism studied to date. As investigators identify new microbes, it would be a relatively simple matter to use standard tools for analyzing the composition of proteins, such as mass spectrometry, to learn which amino acids the organisms contain. Any glaring oddities in the inventory would signal that the microbe could be a candidate for shadow life.

If such a strategy were successful, researchers would face the difficulty of determining whether

[CLOSE-UP]

A Candidate Alien?



While examining 200-million-year-old sandstones extracted from a deep-ocean borehole off the coast of Western Australia, Philippa Uwins of the University of Queensland discovered tiny structures, measuring between 20 and 150 nanometers (billionths of a meter), that appeared to multiply in the laboratory. Tests showed that the structures (*brown globs and tendrils in scanning electron micrograph*) contained DNA, but other scientists dispute the claim that the so-called nanobes are alive.

The vast majority of organisms are microbes, and it is almost impossible to tell what they are simply by looking at them through a microscope.

[THE AUTHOR]

Paul Davies is a theoretical physicist, cosmologist and astrobiologist. He is currently director of Beyond, a research center at Arizona State University devoted to exploring the "big questions" of science. Davies is the author or co-author of 27 books; his latest work is *Cosmic Jackpot: Why Our Universe Is Just Right for Life* (Houghton Mifflin, 2007).

TOM STORY *Arizona State University (Davies)*; PHILIPPA UWINS *Whistler Research Pty./Photo Researchers, Inc. (nanobes)*

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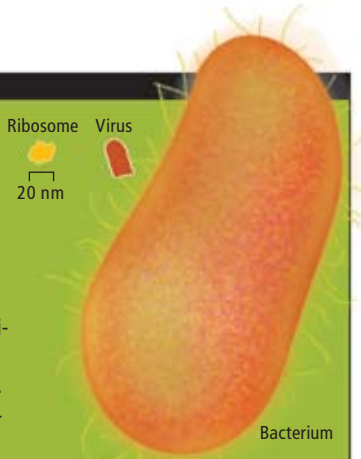
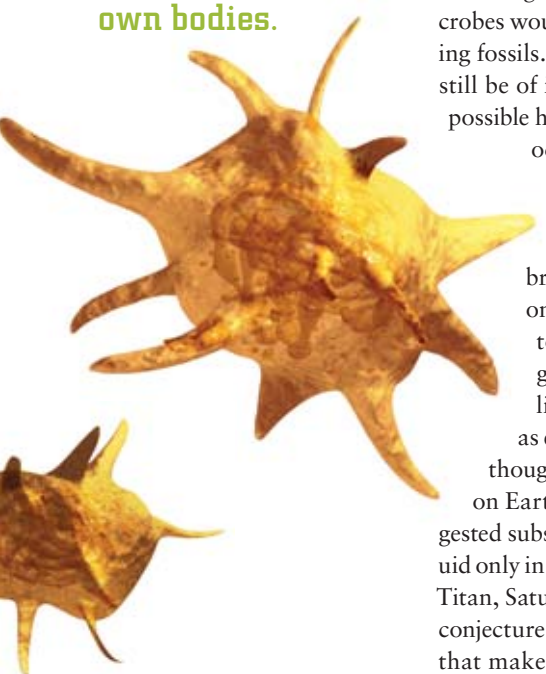
[SIZE LIMITS]

Tiny Aliens

The smallest bacteria have a diameter of about 200 nanometers. Autonomous organisms on our tree of life cannot be much smaller because they must contain protein-building cellular structures called ribosomes, which are each about 20 to 30 nanometers across. But if alien microbes could function without ribosomes, they could be comparable in size to the smallest viruses, which are only 20 nanometers wide. (Viruses do not need ribosomes, because they appropriate the machinery of infected cells to reproduce.)



Perhaps the most intriguing possibility of all is that alien life-forms inhabit our own bodies.



they were dealing with a genuine alternative form of life descended from a separate origin or with merely a new domain of known life, such as archaea, which were not identified until the late 1970s. In other words, how can scientists be sure that what seems like a new tree of life is not in fact an undiscovered branch of the known tree that split away a very long time ago and has so far escaped our attention? In all likelihood, the earliest life-forms were radically different from those that followed. For example, the sophisticated triplet DNA code for specifying particular amino acids shows evidence of being optimized in its efficiency by evolutionary selection. This observation suggests the existence of a more rudimentary precursor, such as a doublet code employing only 10, rather than 20, amino acids. It is conceivable that some primitive organisms are still using the old precursor code today. Such microbes would not be truly alien but more like living fossils. Nevertheless, their discovery would still be of immense scientific interest. Another possible holdover from an earlier biological epoch would be microbes that use RNA in place of DNA.

The chance of confusing a separate tree of life with an undiscovered branch of our own tree is diminished if one considers more radical alternatives to known biochemistry. Astrobiologists have speculated about forms of life in which some other solvent (such as ethane or methane) replaces water, although it is hard to identify environments on Earth that would support any of the suggested substances. (Ethane and methane are liquid only in very cold places such as the surface of Titan, Saturn's largest moon.) Another popular conjecture concerns the basic chemical elements that make up the vital parts of known organisms: carbon, hydrogen, oxygen, nitrogen and phosphorus. Would life be possible if a different element were substituted for one of these five?

Phosphorus is problematic for life in some ways. It is relatively rare and would not have existed in abundance in readily accessible, soluble form under the conditions that prevailed during the early history of Earth. Felisa Wolfe-Simon, formerly at Arizona State University and now at Harvard University, has hypothesized that arsenic can successfully fill the role of phosphorus for living organisms and would have offered distinct chemical advantages in ancient environments. For example, in addition to doing all the things that phosphorus can do in the way of structural bonding and energy storage, arsenic could provide a source of energy to drive metabolism. (Arsenic is a poison for regular life precisely because it mimics phosphorus so well. Similarly, phosphorus would be poisonous to an arsenic-based organism.) Could it be that arseno-life still lingers in phosphorus-poor and arsenic-rich pockets, such as ocean vents and hot springs?

Another important variable is size. All known organisms manufacture proteins from amino acids using large molecular machines called ribosomes, which link the amino acids together. The need to accommodate ribosomes requires that all autonomous organisms on our tree of life must be at least a few hundred nanometers (billionths of a meter) across. Viruses are much smaller—as tiny as 20 nanometers wide—but these agents are not autonomous organisms because they cannot reproduce without the help of the cells they infect. Because of this dependence, viruses cannot be considered an alternative form of life, nor is there any evidence that they stem from an independent origin. But over the years several scientists have claimed that the biosphere is teeming with cells that are too small to accommodate ribosomes. In 1990 Robert Folk of the University of Texas at Austin drew attention to tiny spheroidal and ovoid objects in sedimentary rocks found in hot springs in Viterbo, Italy. Folk proposed that the objects were fossilized "nannobacteria" (a spelling he preferred), the calcified remains of organisms as small as 30 nanometers across. More recently, Philippa Uwins of the University of Queensland has discovered similar structures in rock samples from a deep-ocean borehole off the coast of Western Australia. If these structures indeed arise from biological processes—and many scientists hotly dispute this contention—they may be evidence of alternative life-forms that do not use ribosomes to assemble their proteins and that thus evade the lower size limit that applies to known life.

DANIELA NAOMI MOLNAR (*size comparison*)

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Perhaps the most intriguing possibility of all is that alien life-forms inhabit our own bodies. While observing mammalian cells with an electron microscope in 1988, Olavi Kajander and his colleagues at the University of Kuopio in Finland observed ultrasmall particles inside many of the cells. With dimensions as small as 50 nanometers, these particles were about one-tenth the size of conventional small bacteria. Ten years later Kajander and his co-workers proposed that the particles were living organisms that thrive in urine and induce the formation of kidney stones by precipitating calcium and other minerals around themselves. Although such claims remain controversial, it is conceivable that at least some of these Lilliputian forms are alien organisms employing a radically alternative biochemistry.

What Is Life, Anyway?

If a biochemically weird microorganism should be discovered, its status as evidence for a second genesis, as opposed to a new branch on our own tree of life, will depend on how fundamentally it differs from known life. In the absence of an understanding of how life began, however, there are no hard-and-fast criteria for this distinction. For instance, some astrobiologists have speculated about the possibility of life arising from silicon compounds instead of carbon compounds. Because carbon is so central to our biochemistry, it is hard to imagine that silicon- and carbon-based organisms could have emerged from a common origin. On the other hand, an organism that employed the same suite of nucleotides and amino acids as known life-forms but merely used a different genetic code for specifying amino acids would not provide strong evidence for an independent origin, because the differences could probably be explained by evolutionary drift.

A converse problem also exists: dissimilar organisms subjected to similar environmental challenges will often gradually converge in their properties, which will become optimized for thriving under existing conditions. If this evolutionary convergence were strong enough, it could mask the evidence for independent biogenesis events. For example, the choice of amino acids may have been optimized by evolution. Alien life that began using a different set of amino acids might then have evolved over time to adopt the same set that familiar life-forms use.

The difficulty of determining whether a creature is alien is exacerbated by the fact that there are two competing theories of biogenesis. The first is that life begins with an abrupt and distinctive transformation, akin to a phase transition in physics, perhaps triggered when a system reaches a certain threshold of chemical complexity. The system need not be a single cell. Biologists have proposed that primitive life emerged from a community of cells that traded material and information and that cellular autonomy and species individuation came later. The alternative view is that there is a smooth, extended continuum from chemistry to biology, with no clear line of demarcation that can be identified as the genesis of life.

If life, so famously problematic to define, is said to be a system having a property—such as the ability to store and process certain kinds of information—that marks a well-defined transition from the nonliving to the living realm, it would be meaningful to talk about one or more origin-of-life events. If, however, life is weakly defined as something like organized complexity, the roots of life may meld seamlessly into the realm of general complex chemistry. It would then be a formidable task to demonstrate independent origins for different forms of life unless the two types of organisms were so widely separated that they could not have come into contact (for instance, if they were located on planets in different star systems).

It is clear that we have sampled only a tiny fraction of Earth's microbial population. Each discovery has brought surprises and forced us to expand our notion of what is biologically possible. As more terrestrial environments are explored, it seems very likely that new and ever more exotic forms of life will be discovered. If this search were to uncover evidence for a second genesis, it would strongly support the theory that life is a cosmic phenomenon and lend credence to the belief that we are not alone in the universe. ■

Life from Mars?

If biological determinism—the idea that life must arise under the proper conditions—is true, we might expect life to have emerged elsewhere in the solar system, particularly on Mars (which had liquid water on its surface early in its history). Because Earth and Mars trade material blasted into space by asteroid and comet impacts, a high probability exists that viable microbes, cocooned inside rocks, would have been swapped between these planets. Thus, if life arose from scratch on both Mars and Earth, the resulting organisms would most likely have become intermingled over time. This observation adds an interesting twist to the hypothesis that a "shadow biosphere" of alien life coexists with us: any alien microbes found on Earth might in fact be of extraterrestrial origin. It would make sense to search for such microbial immigrants in terrestrial settings that are Mars-like, such as mountaintops and other cold, dry, high-radiation environments. —***P.D.***

MORE TO EXPLORE

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More information about the shadow biosphere can be found online at **www.astrobio.net/news/article2161.html**

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Making CARBON MARKETS Work

Limiting climate change without damaging the world economy depends on stronger and smarter market signals to regulate carbon dioxide

By DAVID G. VICTOR and DANNY CULLENWARD

KEY CONCEPTS

- We must cut rising world emissions of carbon dioxide to avoid severe climate change.
- Taxes on carbon emissions are effective, but politics discourages their adoption in the U.S. More likely is a federal cap-and-trade market in which polluters get emissions permits and choose how to meet their reduction targets.
- Cap-and-trade markets must be closely managed to be successful, and they cannot do the job without complementary policies that affect emissions. A detailed analysis of the existing European Union carbon market provides valuable insights.

—The Editors

The odds are high that humans will warm Earth's climate to worrisome levels during the coming century. Although fossil-fuel combustion has generated most of the buildup of atmospheric carbon dioxide (CO_2), effective solutions will require more than developing cleaner energy sources and hoping for their wide adoption. Equally important will be establishing institutions and strategies—particularly markets, business regulations and government policies—that will provide incentives for companies to apply innovative technologies and practices that reduce emissions of CO_2 and other climate-altering greenhouse gases.

The challenge is immense. Traditional fossil-fuel energy is so abundant and inexpensive that climate-friendly substitutes have little hope of acceptance without robust policy support. Unfortunately, for nearly two decades negotiations on binding treaties that limit global emissions have produced only meager progress. But that has not stopped policymakers in Europe and other regions where public concern about climate change is strongest from implementing initiatives that offer lessons on how best to curb the planet's high-carbon diet.

Policymakers in the U.S., which historically has produced more CO_2 emissions than any other nation, can in particular learn much about creating functioning carbon-cutting markets by analyzing the ways in which Europe's recent efforts have succeeded and fallen short. We apply such lessons to how the U.S. should construct a national carbon management system, including strategies for establishing markets and other incentives that encourage the development and adoption of low-carbon energy innovations.

Until recently, nearly all debate about creating institutions to protect Earth's climate focused on the global level. Conventional wisdom held that successful climate policy hinges on signing binding international treaties because the activities that cause climate change are

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CARBON CREDIT TRADING aims to reduce greenhouse gas emissions for the lowest cost.

worldwide in scope. If national governments were merely to act alone, without global coordination, industries would simply relocate to where regulation was more lax.

This globalist theory underlay the negotiation of the 1992 United Nations Framework Convention on Climate Change, which called for all countries to work in good faith to address the climate problem and created an organization to oversee the implementation of the treaty's terms. The treaty spawned further attempts to produce climate change agreements, leading to the Kyoto Protocol in 1997. Under Kyoto, the industrialized world—including the U.S., the European Union (E.U.), Japan and Russia—agreed in principle to individually tailored obligations that, if implemented, would cut industrial emissions on average by about 5 percent below 1990 levels. But developing countries, which placed a higher priority on economic growth fueled by unfettered energy use, refused to accept caps on their emissions.

Clean Development Mechanism

Without any practical way to force developing nations to control their emissions, the Kyoto signatories reached a compromise known as the clean development mechanism. Under this scheme, international investors could earn carbon credits for funding projects that would cut emissions in a developing nation even though such countries would face no compulsory restriction on their own output of greenhouse gases. Thus, a British firm that faces strict (and therefore costly) limits on its emissions at home might invest to build wind turbines in China. The British company would then accrue credits for the difference between the "baseline" emissions that would have been released had the Chinese burned coal (the most common energy source in that country) to generate the same amount of electricity and the essentially zero emissions discharged by the wind farm. China would gain foreign investment and energy infrastructure, while the British firm could meet its

[THE AUTHORS]

David G. Victor and Danny Cullenward work at Stanford University's Program on Energy and Sustainable Development (PESD), which is sponsored by BP and the Electric Power Research Institute. Victor, a fellow at the Council on Foreign Relations and a professor of law, is the director of PESD, where Cullenward is a research associate. They have collaborated on numerous topics, including an estimation of the greenhouse gas emissions from hydroelectric dams in tropical regions of the globe.

JAMES PORTO (*top*); NOAH BERGER (*Victor*); KRISTEN TURNER (*Cullenward*)

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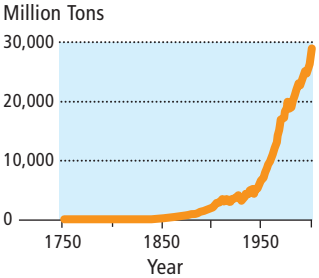
Carbon taxes on emitters avoid the politically charged and corruption-prone process of allocating emissions credits while making transparent the costs of compliance.

[THE PROBLEM]

TOO MUCH CARBON

Rising carbon dioxide emissions from fossil-fuel burning is warming Earth's climate, scientists say, necessitating strong efforts to cut those emissions.

GLOBAL CARBON DIOXIDE FROM FOSSIL-FUEL BURNING



environmental obligations at lower cost; for companies located in industrialized nations, credits earned overseas are often less expensive than reducing emissions at home by adding new technologies to their existing plants and infrastructure.

The market for clean development mechanism credits has since exploded in size, and the exchanges account for about a third of 1 percent of the world's greenhouse emissions—around $4.4 billion in annual value.

Although the Kyoto negotiations rapidly yielded an accord on paper, industrialized nations—where the obligations are most demanding—have implemented the restrictions unevenly. Key countries—notably the U.S. but also Australia and Canada—shunned the Kyoto treaty because they found the requirements either too expensive or politically inconvenient. Hence, the overall impact of the treaty on the global warming problem has never reached its potential, which would have been minor even if all nations had complied with its mandates. Broad international treaties often suffer these difficulties because, in the interest of reaching an accord, they reflect the interests of their least enthusiastic participants and usually offer easy escape clauses to those that will not adhere to their agreements.

Evaluating Climate Policy

Because of the challenge of setting meaningful global goals, the development of an international system that can slow climate change is only just starting now, nearly a decade after Kyoto. Effective policy is emerging from a core group of countries that are most committed to regulating emissions. In contrast to the integrated global approach envisioned at Kyoto, every nation has formulated a different strategy to control release of greenhouse gases. The diversity of plans reflects individual nations' deep uncertainties about the best ways to manage emissions as well as huge variations in the capabilities and styles of governments.

The efforts to limit greenhouse gas emissions within the E.U. are key because the withdrawal of the U.S. from Kyoto left the E.U. as the largest political entity following a comprehensive plan for regulation. The European system features the strongest institutions and exchanges the greatest volume of credits. For 55 percent of its total emissions (produced mainly by buildings and the transportation sector), the E.U. and its member states have extended existing policies to boost energy efficiency. These rules include, for instance, voluntary (soon to be binding) automotive fuel economy targets that were negotiated with carmakers.

The remaining E.U. greenhouse gas sources—defined as producers of "industrial emissions," including power plants—are fewer and larger, and thus easier to control. For these business segments, European regulators designed a continent-wide market structure, called the emission trading scheme, a so-called cap-and-trade system modeled on a successful program created by the U.S. during the 1990s to reduce sulfur dioxide, the main cause of acid rain. Under the E.U. arrangement, every government allocates emissions credits—each credit representing permission to release a ton of carbon dioxide gas—to its industrial plants. The credits are given to emitters mainly for free up to some limit that is calculated according to the nation's assigned emissions ceiling. The companies then decide individually whether it is cheaper to reduce their emissions, which would free up extra permits for them to sell, or to buy permits from others on the open market. Companies and governments can also purchase credits from the clean development mechanism and from a similar scheme that generates credits in Russia and other former Eastern Bloc countries.

If emissions cuts prove costly, demand for permits will rise and so will their prices. Alternatively, prices will fall if low-cost technologies for reducing CO_2 release appear or if slow economic growth weakens the industries that emit the gas. By limiting the total number of permits, E.U. regulators fix pollution levels while the market sets the price. The trial period for the new European market runs from 2005 through the end of this year.

The establishment of a carbon market, like any market that involves awarding novel property rights, hinges on political choices. Politicians and the interested industries typically press for trading markets rather than taxes, because political systems tend to award most emissions credits for free. Taxes, in contrast, impose many more visible costs.

In the past, a few trading systems have auctioned some of their permits, but "big carbon"—including coal-mining firms and owners of coal-fired power plants—is organizing to resist such attempts. In the E.U., governments have agreed to give away most of the credits for free to existing emitters; most of the proposed climate legislation in the U.S. would require a similar handout. In other situations in which govern-

JEN CHRISTIANSEN; SOURCE: GREGG MARLAND, BOB ANDRES AND TOM BODEN *Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory*

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[A MARKET-BASED SOLUTION]

THE CARBON TRADE

Under the Kyoto Protocol, which came into force in February 2005, most industrialized nations have agreed to cut existing total greenhouse gas emissions by an average of 5.2 percent (compared with 1990 levels) between 2008 and 2012. Each participating government has its own national target for reducing carbon dioxide emissions.

Carbon trading is a market mechanism that is intended to tackle climate change. The key concept is that, from the planet's point of view, the sources of CO_2 are far less important than the total amounts released. Rather than rigidly forcing emissions reductions country by country, new carbon markets create a choice for polluters: either pay to cut the emissions of their own equipment or continue releasing CO_2 and pay others—in some cases, organizations in the developing world where costs are often less—to lower their greenhouse gas output. In theory, this approach lessens climate warming discharges at the minimum price tag.

Carbon exchanges occur in two ways. The first is a cap-and-trade market whereby emissions are limited and polluters receive tradable emission credits or permits (*top*); each represents a metric ton of allowed CO_2 emissions. In 2005 the European Union established the emission trading scheme, a mandatory cap-and-trade system for European companies. Today the E.U. system is the world's largest carbon market.

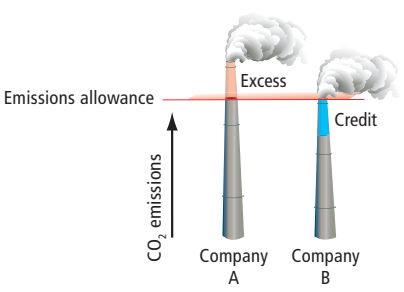
The second main method to trade carbon is through credits from projects that compensate for, or offset, emissions (*bottom*). The Kyoto Protocol's clean development mechanism, for instance, allows industrialized countries to gain credits by financing low-carbon-output projects in developing countries.

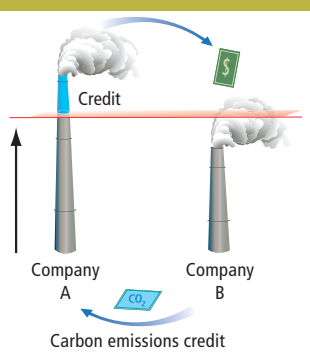
The extent of carbon trading worldwide is not well quantified, because carbon markets are still fairly new, transaction data are not readily available, and several different schemes exist. The World Bank, however, estimates that the value of carbon traded in 2006 was about $30 billion.

—D.G.V. and D.C.

CAP-AND-TRADE MARKET

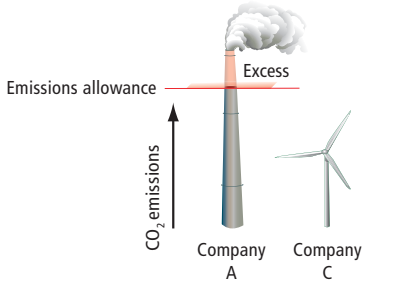
Say that company A is releasing more CO_2 than its assigned limit, whereas company B is emitting less than its allowance (*left*). Company A can pay company B for its unused permits and thus use them to meet its obligations (*right*).

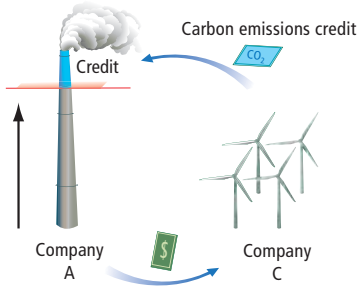




OFFSET EXCHANGE

Imagine that company A is over its emissions allotment. Through Kyoto's clean development mechanism, company A can invest in a carbon reduction project established by company C in a developing nation, which costs less than a similar project in the developed country (*left*). Company A gets the credits it needs at a reduced cost, and company C gets investment money it needs, while less total CO_2 enters the atmosphere than if the developing country had turned to a fossil-fuel energy source (*right*).





ments have doled out property rights to private entities (cell phone licenses, for example), administrators have not encountered such severe political opposition to auctions because industry is not already exploiting the public assets; the fossil-fuel industry, by contrast, has long been free to emit greenhouse gases into the air. Pollution markets are legal fiats: they are designated as valuable property where none existed before. Participants in new carbon markets stand to gain or lose depending on the formulation of the rules for allocating credits. When it comes to assigning property rights for assets that are already held, politically inspired handouts, not auctions, are the usual rule.

Some of these handouts are politically expedient because they help get a market started where entrenched interests—such as the coal lobby—would otherwise block progress. But if all the credits are given away, entrenchment of big carbon and old technologies becomes a bigger danger.

Given these circumstances, it is no surprise that the E.U. carbon market has suffered several teething problems during its short history. In many cases, the permit allocation plans devised by each government have arrived past deadline and have not covered all the emitters. But the most controversial aspect is that politics have often favored certain firms or business sectors

LOGAN PARSONS AND ANN SANDERSON

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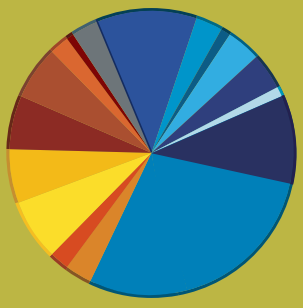
[CARBON OFFSETS]

FINANCING GREEN PROJECTS OFFSHORE

The clean development mechanism (CDM), an arrangement under the Kyoto Protocol, lets firms in industrialized nations invest in greenhouse gas reduction projects in developing countries as an alternative to more costly efforts in their own countries. Such deals provide the investing companies with emissions reduction credits. The pie charts (*below left*) describe the types and locations of the 1,534 projects in the CDM pipeline. Critics rightly argue that some emissions reductions under the CDM (notably those aimed at HFC-23) are fraudulent, permitting, for example, the CDM to pay $12.7 billion (through 2012) for HFC-23 projects that should have cost only about $136 million [*see box on page 76*].

EXISTING CDM-FINANCED PROJECTS
Breakdown of Projects in CDM Pipeline



CO_2-Lowering Projects

- Waste heat 3%
- Cement processing 2%
- Biomass fuels 7%
- Hydropower 6%
- Wind power 6%
- Combined gas turbine 6%
- Fuel switching 2%
- Energy efficiency 1%
- Other 3%

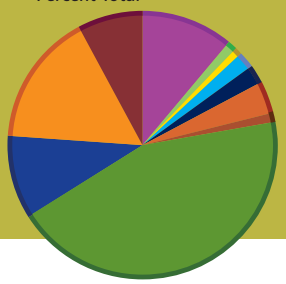
Other Waste Gas Projects

Methane
- Landfill 11%
- Livestock 3%
- Wastewater 1%
- Oil field 4%
- Coal mine 4%

Nitrous oxide
- Nitric acid 1%
- Adipic acid 10%

- HFC-23 from refrigerant manufacturing 28%

AVERAGE ANNUAL CARBON CREDITS BY HOST COUNTRY
Percent Total



Countries

- South Korea 8%
- India 16%
- Brazil 10%
- China 44%
- South Africa 1%
- Mexico 4%
- Chile 2%
- Argentina 2%
- Qatar 1%
- Malaysia 1%
- Others 9%

GREENHOUSE GASES released in the developed world (*top*) can be offset by low-carbon output in developing nations (*bottom*).

ANN SANDERSON (*graphs*); CHRISTOS BLETSOS *epa/Corbis (top photograph)*; MICHAEL S. YAMASHITA *Corbis (bottom photograph)*

or have pumped the market with cheap and questionable emissions credits obtained from the clean development mechanism. The German government, for example, keen to protect its coal industry, awarded too many free credits to coal-fired electric power plants. The owners of such plants then charged customers for carbon "costs" the owners never had to pay. Similar malfeasance has occurred in other countries, including the Netherlands, Spain and the U.K.

In principle, the E.U. reviews each government's allocation of credits so that favored companies are not subsidized unfairly. In practice, however, member states hold most of the political cards and are not hesitant to deal them as they deem fit. The E.U. system now envisions reallocating permits possibly every five years, which would deliver fresh handouts each round and make it harder to dislodge the high-carbon technologies that cause most of the emissions.

The successful U.S. acid rain reduction program, although it also allocated nearly all its credits free of charge, has kept its core rules stable for nearly two decades, which has made it much easier for the marketplace to function properly.

The E.U. has also encountered trouble in ensuring that emitters, brokers and traders get access to timely and accurate information on the supply and demand of carbon credits. During the emission trading scheme's trial period, confusion in the market caused prices to gyrate from almost $40 per ton of CO_2 at the outset to about $1 per ton today. The loss in value resulted when it became clear that E.U. governments had massively oversupplied the market with permits, much as poorly managed central banks can cause inflation by printing excess money. To combat the problem, the E.U. tightened the screws for the next trading period (2008 to 2012), which has sent the price for those permits to about $30.

Growing Markets Worldwide

The E.U. experience teaches that trading systems, like all markets, do not arise spontaneously. Economic historians have determined that markets

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require strong underlying institutions to assign property rights, monitor behavior and enforce compliance. The E.U. has long kept track of other pollutants (such as sulfur and nitrogen oxides) emitted by exactly the same industrial sources. Likewise, European administrative law systems have a long history of effective enforcement. Absent these institutions, emissions credits in Europe would be worthless.

The central role of institutions and local interests accounts for why different parts of the world have developed many different carbon trading systems. Indeed, a worldwide carbon market is emerging from the bottom up, rather than from the top down via an international treaty mandate such as the Kyoto Protocol, which means it will probably take many decades to establish a truly global system.

When the U.S. establishes a national trading system, the scale of U.S. emissions trading could supplant the dominance of the E.U. in the budding global carbon market. Exactly how the U.S. market unfolds will be complicated by the ad hoc nature of its development. Several states in the Northeast and the West, weary of the federal government's inaction, are moving to create their own carbon trading systems. We doubt that these state systems will survive intact once a federal plan is in place, not least because electricity generation (which produces significant quantities of CO_2) is fungible across large segments of the country's power grid and not easily amenable to a state-by-state approach. Nevertheless, some states may retain stricter rules, which could result in a national patchwork of trading systems.

Wooing the Reluctant

In the meantime, emerging nations—such as China and India—pose the toughest obstacles to expanding emissions trading systems because they prioritize economic growth and rely heavily on fossil fuels. Carbon dioxide emissions from these countries are already rising at roughly three times the developed world's rate. Total output from emerging nations will exceed that of the industrialized West within the next decade; China is currently the world's largest single emitter. Moreover, emerging countries' economies often rely on obsolete technologies that offer the opportunity, at least in theory, to save money if newer emissions controls are applied.

Forcing less developed countries to join a full-blown international emissions trading system would be unwise. Wary of economic constraints, yet unsure of their future emissions levels and the costs of stanching the flow, these states would demand generous headroom to grow. Agreeing to such a strategy, though well intentioned, would involve giving them lax emissions caps, which would undercut efforts to control emissions elsewhere in the world because surplus permits would flood global markets.

Rather than trying to compel these nations to apply an emissions cap they would reject, the clean development mechanism reflected a compromise that theoretically promises to constrain trading to areas where developing countries have made actual cuts. And because the E.U. possesses the biggest market for emissions credits, the clean development mechanism's prices have converged on those set there.

The central role of institutions and local interests accounts for why different parts of the world have developed different carbon-trading systems.

Manipulating the Market

In reality, however, the concept that underpins the clean development mechanism has a dark side that casts a shadow over the integrity of all

[PITFALL #1]

MARKETS FROM THIN AIR

When a government sets up a market to trade carbon dioxide, the process involves awarding property rights where none existed before. Unfortunately, politically connected firms often have received preferential treatment, leading to financial windfalls. When the European Union's emission trading scheme was being established, for example, the German government awarded free emissions credits to coal-fired electric power plants, whose politically influential owners then charged customers for carbon "costs" they themselves never had to pay.

When such markets are formed, the quantity of carbon credits issued must match the real output of carbon emissions, which can be difficult to assess. If too many permits are allocated, a fall in the value of each permit eventually results when the overallotment becomes known, which is essentially what occurred in the E.U.'s emission trading scheme after April 2006 (*graph*).

To avoid many of these problems, emissions permits should be auctioned off to the highest bidders. An even better strategy would be to institute a carbon tax program, which would avoid the politically charged and corruption-prone process of allocating valuable property rights while also making transparent the costs of compliance—so energy producers could gauge how much they need to invest. ***—D.G.V. and D.C.***

PRICE VOLATILITY of carbon emissions credits was exacerbated when European nations allotted too many permits to domestic polluters, which allowed their value to inflate until the overallocations became known to traders in 2006.

RISE AND FALL OF EUROPEAN CREDIT PRICES
Dollars per Ton of Carbon Dioxide

JEN CHRISTIANSEN

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[CARBON VOLUMES]

TRADES VS. EMISSIONS

The quantity of greenhouse gases traded in all carbon markets each year pales in comparison to annual global emissions.

The numbers below refer to millions of metric tons (CO_2 equivalent):

49,000
Total global greenhouse gas emissions in 2004

1,597
Total world carbon trades in 2006

To place the lower number in context: If a midsize car emits around five metric tons of CO_2 a year, the global carbon market is equivalent to the annual CO_2 output of 300 million autos. (The U.S. has about 250 million passenger vehicles.)

carbon markets. Investors have found it difficult to identify the baseline emissions values for many projects—the business-as-usual scenario against which new project emissions are compared. So they have instead focused on projects to install marginal so-called end-of-pipe technologies rather than on more fundamental changes in energy systems that would actually release fewer greenhouse gases. For example, about a third of the clean development mechanism pipeline credits stem from projects aimed at controlling just one industrial gas, trifluoromethane, or HFC-23, a manufacturing by-product that, as a greenhouse gas, is about 12,000 times as strong as CO_2 [*see box below*].

The problem lies in how best to halt HFC-23 releases in developing nations. All the plants in the industrialized world have installed inexpensive devices to remove the chemical, and leading firms have shared that technology with all comers. But manufacturers in the developing world have discovered that holding off on installation allows them to keep their baseline values high. In so doing, they earn generous clean development mechanism credits with prices set at the high European levels—prices that are not connected to the actual cost of the upgrades for remaining HFC-23. As a result, investors in these projects will reap up to a total of $12.7 billion through 2012, according to attorney Michael Wara, our colleague at Stanford University, when only $136 million is needed to pay for the HFC-23-removal technology.

A better approach for dealing with HFC-23 and other industrial gases would be for developed nations simply to pay directly for the necessary equipment. The successful Montreal Protocol employed this method to preserve the ozone layer. The E.U. has further exacerbated the clean development mechanism debacle by honoring any credit that is approved under the mechanism's rules, which are set through a cumbersome committee process under the Kyoto Protocol. As the U.S. establishes its own carbon market, it should force these bogus permits from the market by setting its own tighter rules to govern whether participants can gain credit from the clean development mechanism and other such offset programs.

An improved clean development mechanism will not be enough to get developing countries engaged, and pressing them to cap their emissions will likely backfire. A more effective strategy would be to focus on situations in which these countries' existing interests align with the goal of cutting carbon. China, for example, driven by worries over energy security, has moved to boost energy efficiency. Analysts believe that plausible policy changes could cut CO_2 emissions by a billion tons a year through 2020. Meanwhile calculations made by our research program suggest that India's push for an expanded civilian nuclear power program could lower carbon emissions by as much as 150 million tons a year. By comparison, the entire E.U. effort to meet the Kyoto targets will reduce releases by only about 200 million tons annually, and all the projects in the clean development mechanism add up to savings of about 170 million tons per annum.

A Five-Step Plan

Given the scale of the climate challenge and the consequences of delay, we recommend five steps toward a more effective strategy.

First, the U.S. should establish a mandatory tax policy to control the output of greenhouse gases. Instead of a cap-and-trade system, simply taxing CO_2 emitters avoids the politically charged and corruption-prone process of allocating valuable property rights while also making clear the long-term costs of compliance so

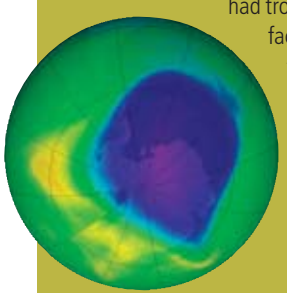
SOURCE: KARAN CAPOOR AND PHILIPPE AMBROSI IN *STATE AND TRENDS OF THE CARBON MARKET 2007*. WORLD BANK PAPER IN COOPERATION WITH THE INTERNATIONAL EMISSIONS TRADING ASSOCIATION, WASHINGTON, D.C., MAY 2007 (*carbon trade volume*); NASA (*ozone hole*)

[PITFALL #2]

GAMING THE SYSTEM

Nascent markets based on government-assigned property rights all face the same problems—equitable distribution of trading information and misuse of the rules of the game. Buyers who have more complete information earlier than others can purchase a property very cheaply before it is correctly valued and then profit when that property gains in value. That occurred when the Kyoto Protocol's clean development mechanism started operations. Permits purchased for little by those in the know suddenly grew more expensive when demand from newly aware polluters started to rise; as a result, early buyers made a killing.

The CDM also suffered from artificial manipulation when investors found that they had trouble determining the (baseline) quantities of emissions existing facilities were releasing so they could compare them against those produced by the planned carbon-reduction projects. So the investors instead concentrated on efforts to install marginal "end-of-pipe" technologies rather than implementing more basic changes in industrial systems. Hence, about a third of CDM credits relate to projects designed to cut emissions of a strong greenhouse gas—trifluoromethane, or HFC-23 [*see box on page 74*]. Low-cost intervention can stop HFC-23 release, but companies in the developing world have found that holding off on installation allows them to inflate their baseline values. Such delays have let them garner CDM credits at high European prices—values not connected to the actual cost of the HFC-23 abatement effort. Thus, these firms have reaped billions of dollars, although the investment for the entire HFC-23 effort was valued only in the hundreds of millions of dollars. ***—D.G.V. and D.C.***



CLOSING THE OZONE HOLE by replacing CFC refrigerants with HCFCs resulted in a climate-warming waste by-product, HFC-23, that also had to be eliminated.

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that industry can plan more efficiently. The price volatility of cap-and-trade systems impedes wise planning.

Second, should Congress prefer a cap-and-trade system, a smart compromise would be to create a so-called safety valve that places a ceiling on prices of credits so that industry has some certainty about the cost of compliance. (In practice, the government would accomplish this by promising to supply additional credits at a fixed price. The extra credits probably would have little impact on the total quantity of emissions released, whereas the resulting price stability would bring substantial economic benefits.) This price, which essentially transforms the trading scheme into a tax, must be set high enough so that it sends a credible signal that emitters must invest in technologies and practices that lower carbon emissions. And under any cap-and-trade system, it is crucial that all credits be auctioned publicly. Politically, it may be essential to hand out a small fraction of credits to pivotal interest groups. But our planet's atmosphere is a public resource that must not be given away to users.

Third on our list of recommendations, industrialized countries must develop a smarter strategy for engaging emerging markets. Purchasers of clean development mechanism credits—notably the E.U. and Japan—need to lobby the mechanism's executive board for comprehensive reform. Their lobbying will be more effective if they also restrict access to their home markets to credits from the clean development mechanism that have firmly established baselines that entail bona fide reductions. As it plans a climate policy, the U.S. should establish its own tighter rules regarding such credits. And the dozen or so largest emitters should convene a forum outside the Kyoto process to find more flexible and effective strategies that engage developing countries in slowing (and eventually reversing) their growth in carbon emissions. Seriously engaging developing countries will require complex packages of policy reforms that are tailored to each country's situation. These reforms must be implemented by working with finance and industrial ministers, rather than environmental bureaucrats who rarely call the shots.

Fourth, governments must accept that market-based price signals will not be enough to solve the problem. Encouraging more efficient use of energy requires, for example, not only higher energy prices but also equipment standards and mandates because many energy users (especially residential users) are insufficiently responsive to price signals alone. Governments should encourage the use of low-carbon power from any source, be it renewable or nonrenewable.

Finally, governments must adopt active strategies to invent and apply new technologies, such as advanced coal-fired power plants that inject their CO_2 emissions safely underground. The formulation of such plans must confront what we call the "price paradox." If today's European carbon prices were applied to the U.S., most utilities would not automatically install new power generation technologies, according to a study by the Electric Power Research Institute. In much of the U.S., conventional coal-fired power plants would still be cheaper than advanced coal technology, nuclear power, wind farms or turbines fired with natural gas. Raising carbon prices to perhaps $40 per ton of CO_2 or higher would encourage greater adoption of new technology, but that possibility seems politically unlikely. Solutions will require special funding for commercialization of useful technologies, as well as a careful, across-the-board review of the factors stifling change, such as uncertainty about how governments would regulate new power plants.

To succeed, the world must make progress on all five of these fronts. Although we need to get the science and engineering right, the biggest danger lies in failing to craft human institutions and policies that encourage people to reduce their emissions of greenhouse gases. ■

[STEPS TO SUCCESS]

WAYS TO CURB CARBON

1. The U.S. government should institute a mandatory tax policy to control emissions. Taxes provide clear, long-term price signals so companies can invest intelligently to lower carbon emissions. In contrast, the price volatility inherent in cap-and-trade systems hinders planning. Tax systems reduce opportunities for political favoritism and corruption. And taxes are easier to adjust when required.

2. If the U.S. sets up a cap-and-trade system, it should create a safety valve that will establish a price ceiling on carbon permits so that firms can reliably estimate compliance cost. All credits under a cap-and-trade system must be auctioned off to avoid political favoritism.

3. Industrialized nations must find ways to engage emerging countries in carbon emissions reduction. This process will require complex packages of policy reforms that are tailored to each country's specific circumstances.

4. Real leverage on emissions will require a combination of market-based climate policies (such as carbon taxes and smarter trading schemes) and regulations that accelerate the adoption of new technologies.

5. Governments must formulate active strategies to invent and demonstrate new large-scale, low-emissions energy systems.

—D.G.V. and D.C.

MORE TO EXPLORE

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SCI AM A longer version of this article is available at **www.SciAm.com/ontheweb**

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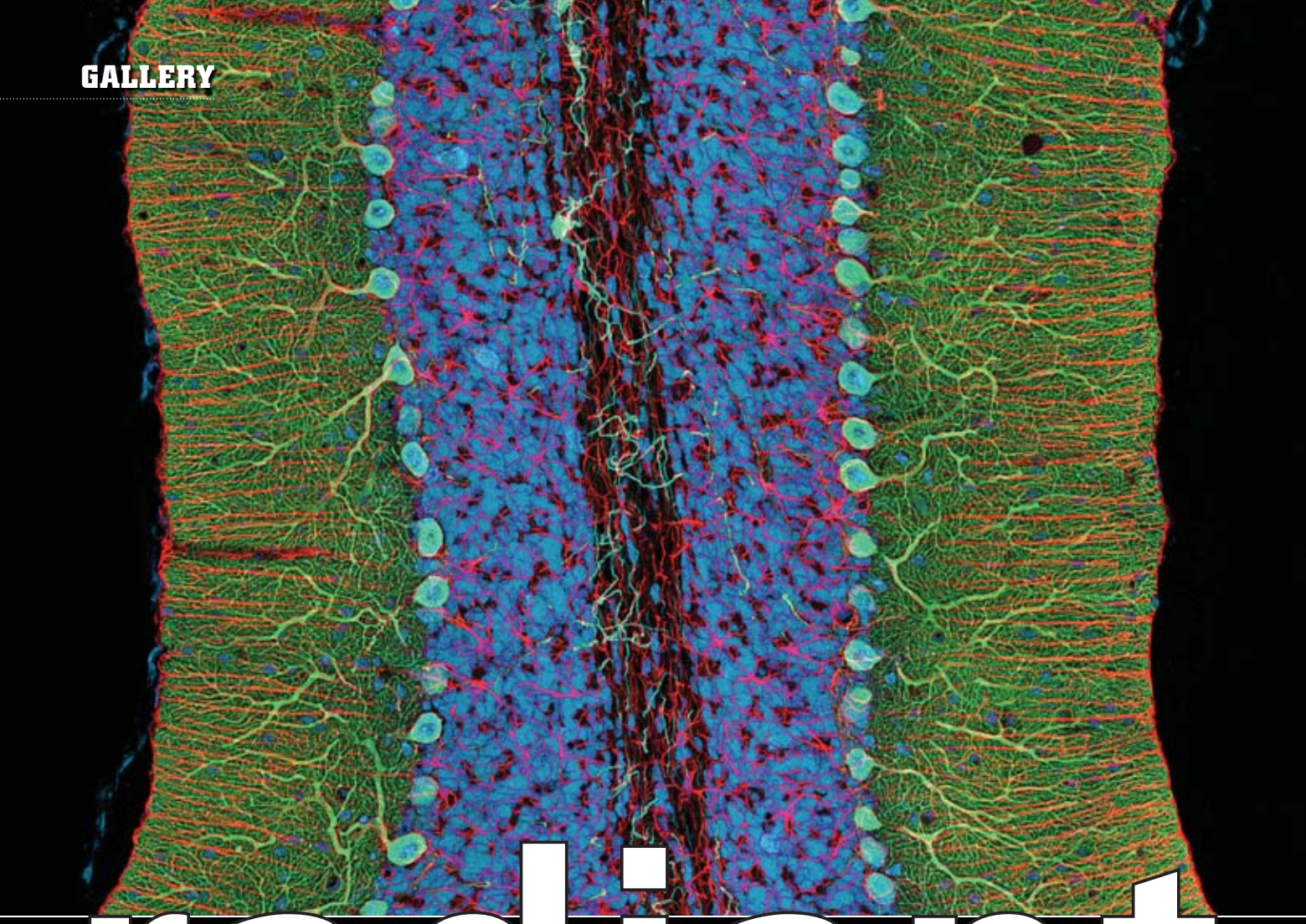

radiant

State-of-the-art light microscopy illuminates the exquisite details of life

By Emily Harrison

BRIGHT BRAINS: Thomas Deerinck of the University of California, San Diego, captured fine anatomical details of a 400-micron (μm) sample of rat cerebellum (*above*), coloring the Purkinje neurons green, the glial cells red and the nuclei blue (2-photon microscopy). Jean Livet of Harvard University imaged a 340-μm brain stem section from a mouse genetically engineered so that each neuron is a distinct color (*opposite page*). This "Brainbow" colorizing technique can reveal the routes of individual axons through the brain's complicated wiring (confocal microscopy).

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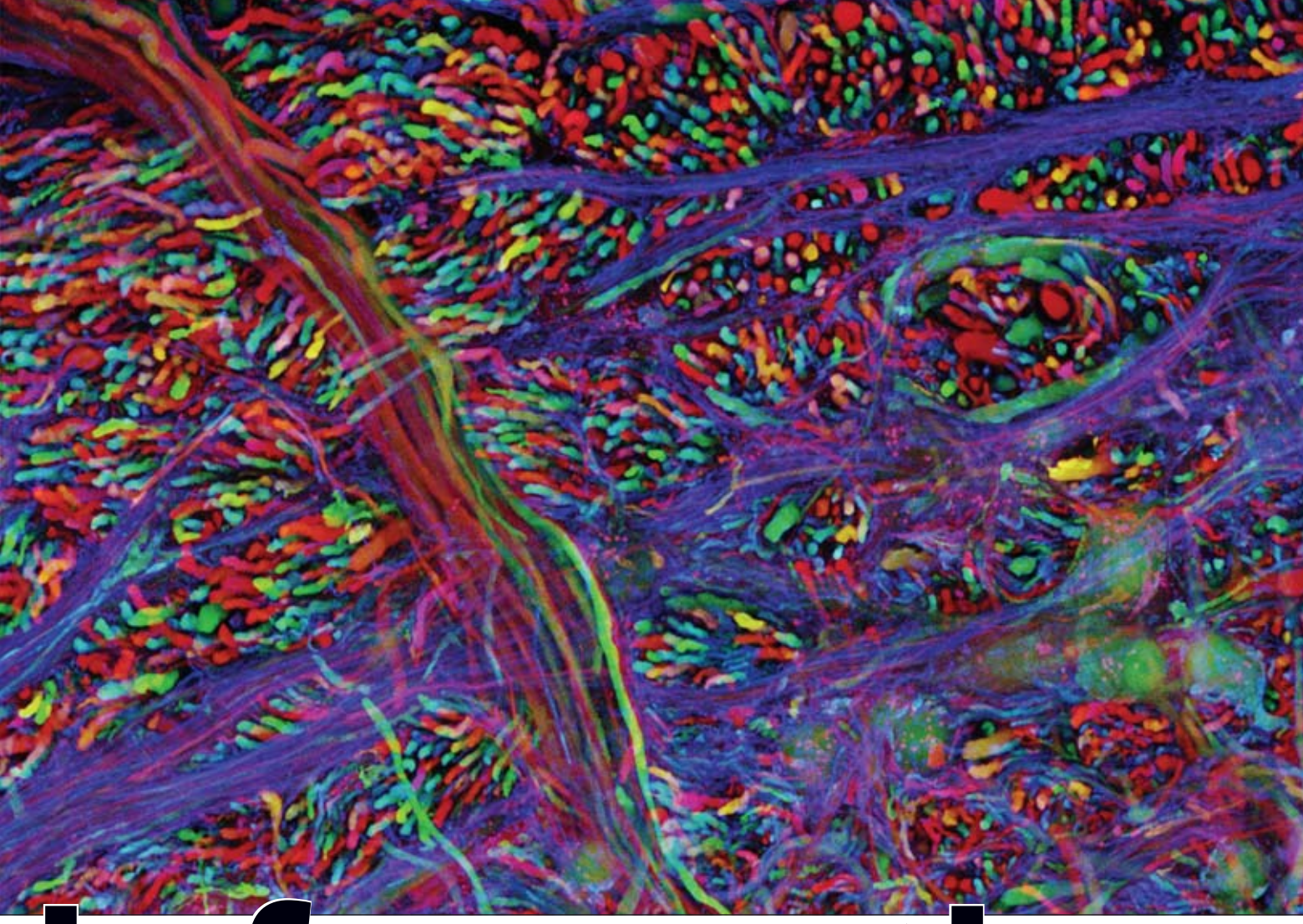

information

For all the delights and horrors human vision provides, it has only one way of collecting information about life: cells in the retina register photons of light for the brain to interpret into images. When it comes to seeing structures too small for the eye to resolve, ones that reflect too few photons for the eye to detect, microscopy must lead the way. The images displayed here, honored in the 2007 Olympus BioScapes Digital Imaging Competition for both their technical merit and their aesthetics, represent the state of the art in light microscopy for biological research.

Call it a renaissance, call it a revolution; in the field of light microscopy, it is well under way. Palettes of light are diversifying as scientists develop new fluorescent markers and new genetic techniques for incorporating them into samples, throwing open doors to discovery. For example, the researchers responsible for this year's first-prize image employed a new technique, called Brainbow, to turn each neuron in a mouse's brain a distinct color under the microscope. The method allows them to trace individual axons through a dizzying neuronal mesh and to map the wiring of the brain in a way that was impossible using earlier imaging techniques.

The precision of the tools is changing, too. Individual proteins can be tagged to watch how a molecule walks, and the minute details of cell division and differentiation can be witnessed live. Microscopists can paint fast in broad strokes of light to capture ephemeral events or more slowly in tiny strokes of light to see a piece of life in exquisite detail. And with new innovations in microscope technology, the lacuna between imaging speed and resolution continues to narrow.

The ability to see even the smallest biological structures with a range of techniques and to manage the massive amounts of resulting data builds a powerful, intimate portfolio of life—accessible to all and deeply meaningful to those who understand and wonder at its details.

Emily Harrison is photography editor at Scientific American.

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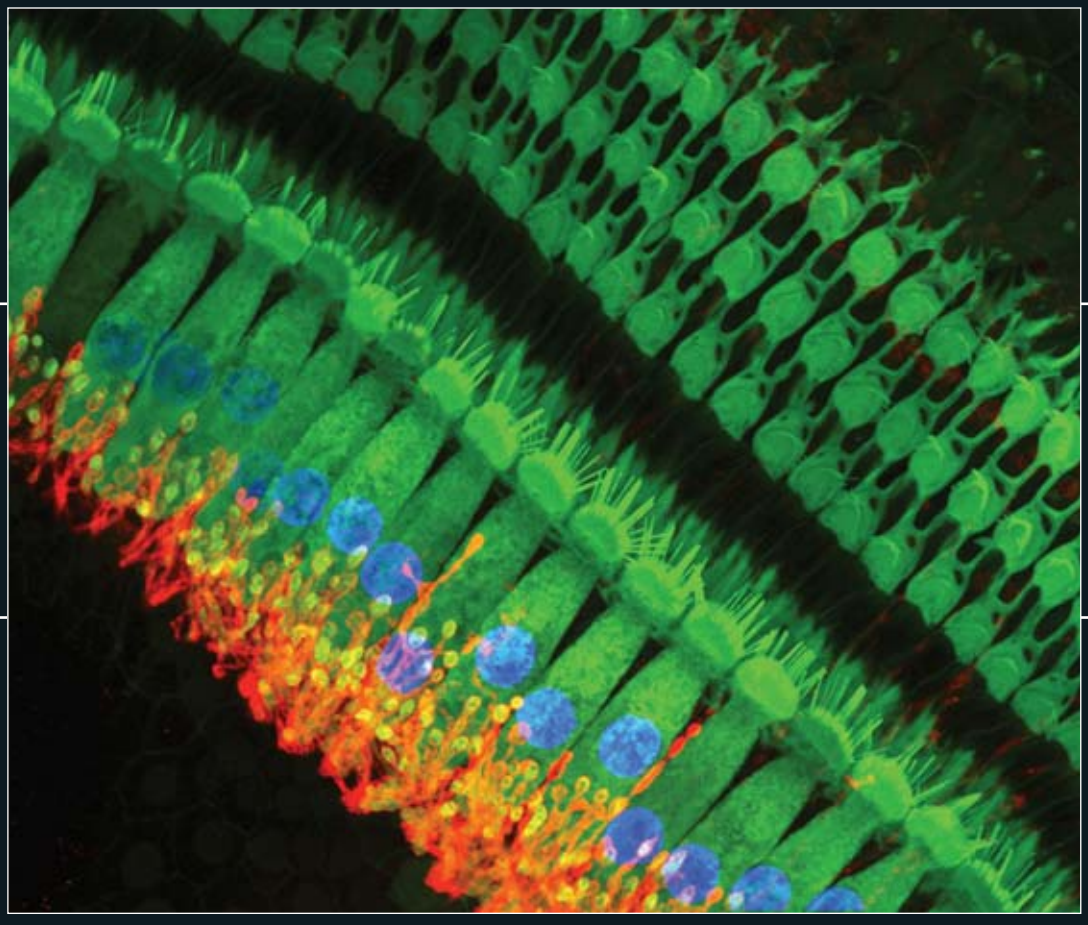

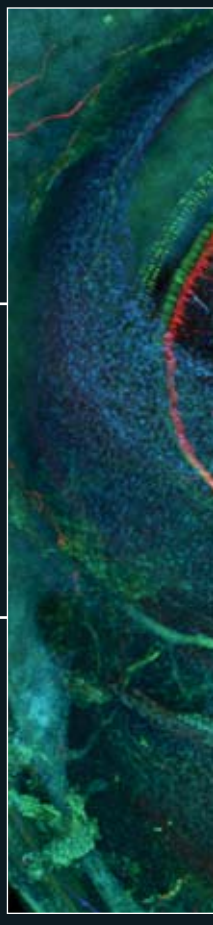

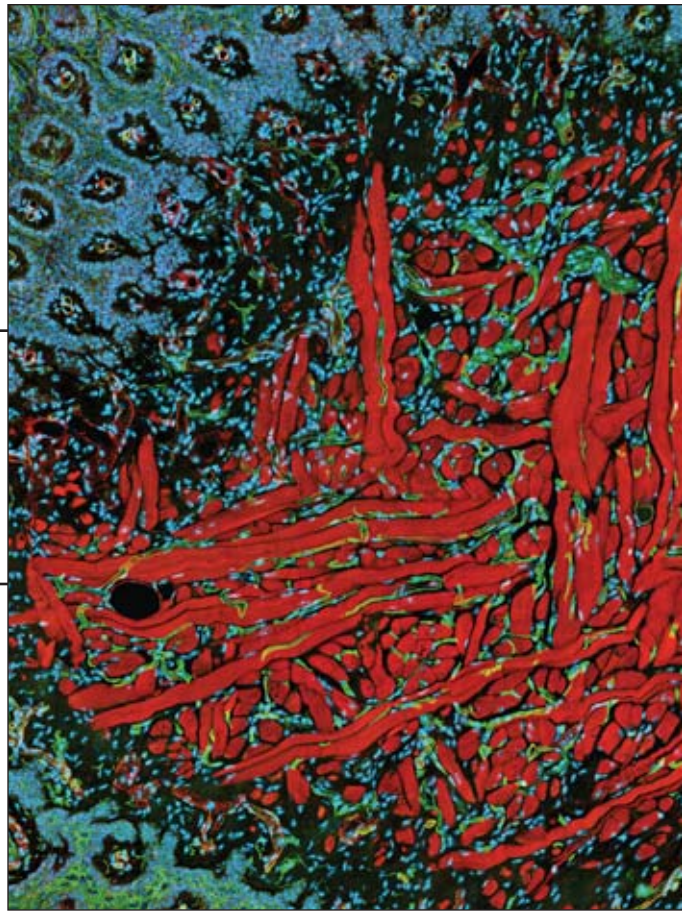

MUSCLE CELLS make a mighty fabric, which Thomas Deerinck of the University of California, San Diego, showed in a cross section of the striated tissue of a rat tongue (*right*) (confocal). Muscle fibers from a drosophila larva (*far right*), magnified under the microscope by Hermann Aberle of the University of Muenster in Germany, are chaotically arranged because of a genetic mutation (confocal).

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

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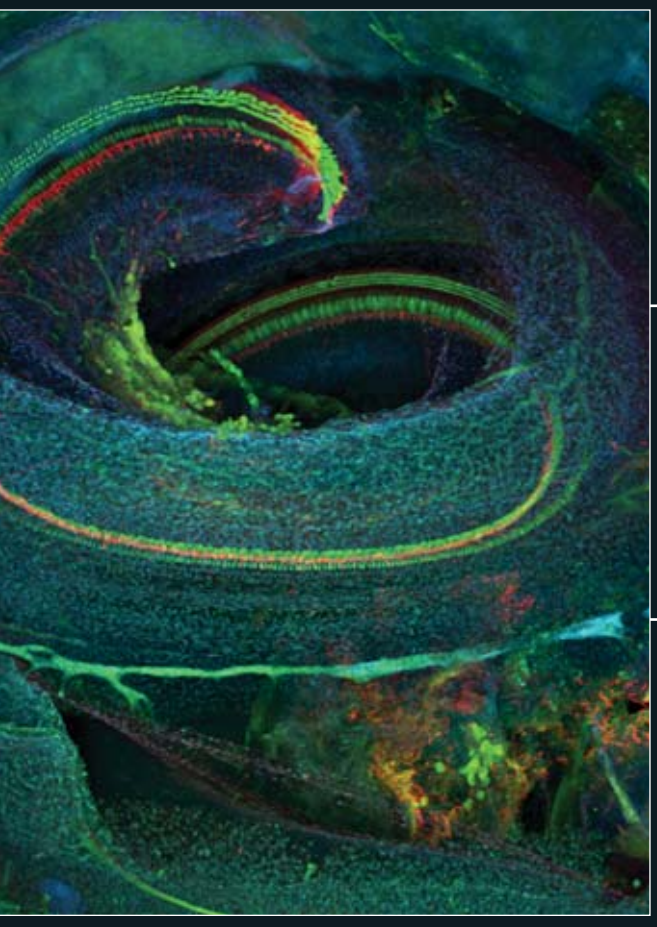
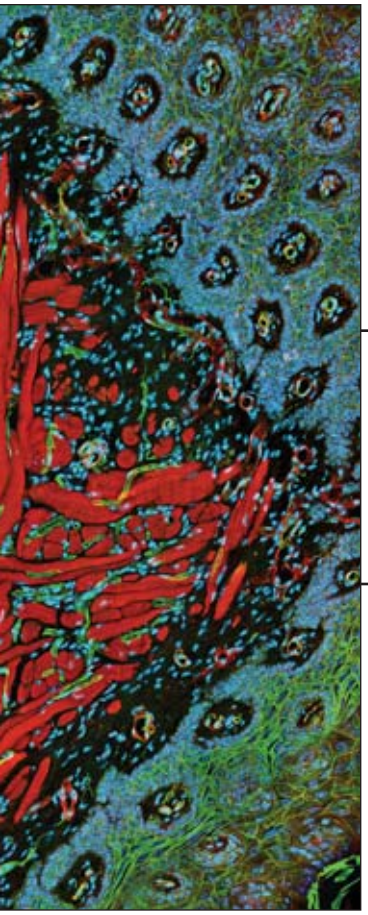
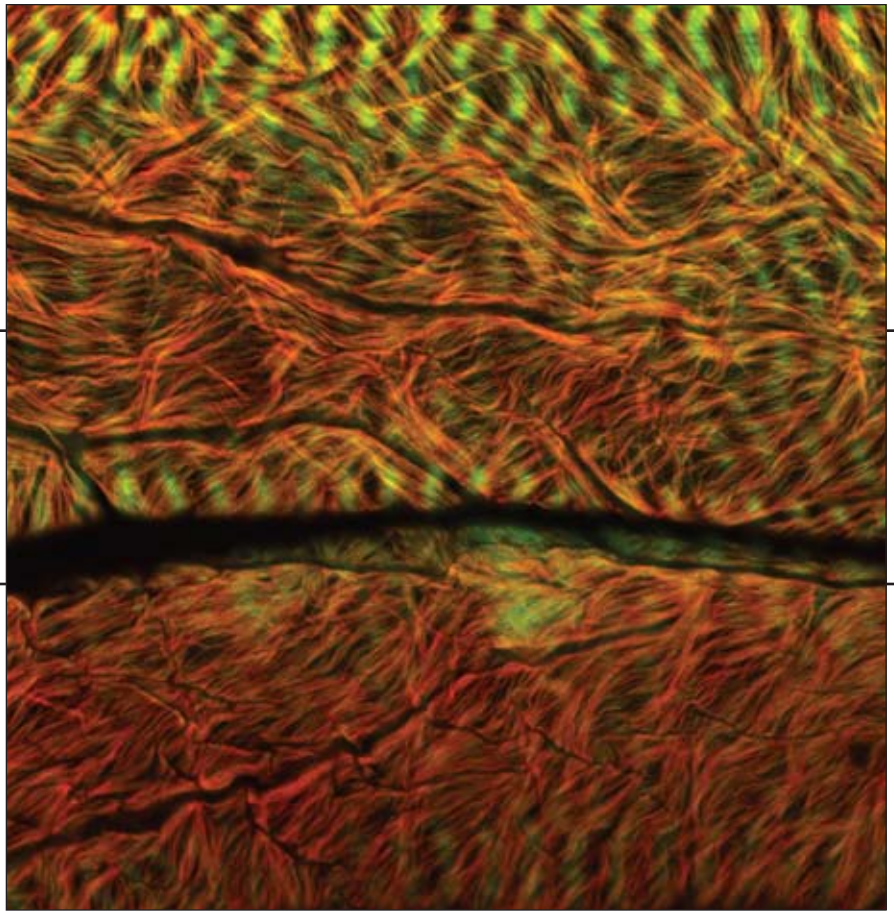


INNER-EAR STRUCTURES are difficult to visualize because they reside in a region that is tiny and difficult to isolate. At the far left, Sonja Pyott of the University of North Carolina Wilmington presents a clear view of rat inner-ear hair cells, which turn mechanical sound into electrical signals. The cells are green, the synaptic contacts with other cells red and the nuclei blue (confocal). Coloring the elements similarly in the other image, Glen MacDonald of the University of Washington produced an ethereal 642-μm-deep view of a mouse inner ear (confocal).





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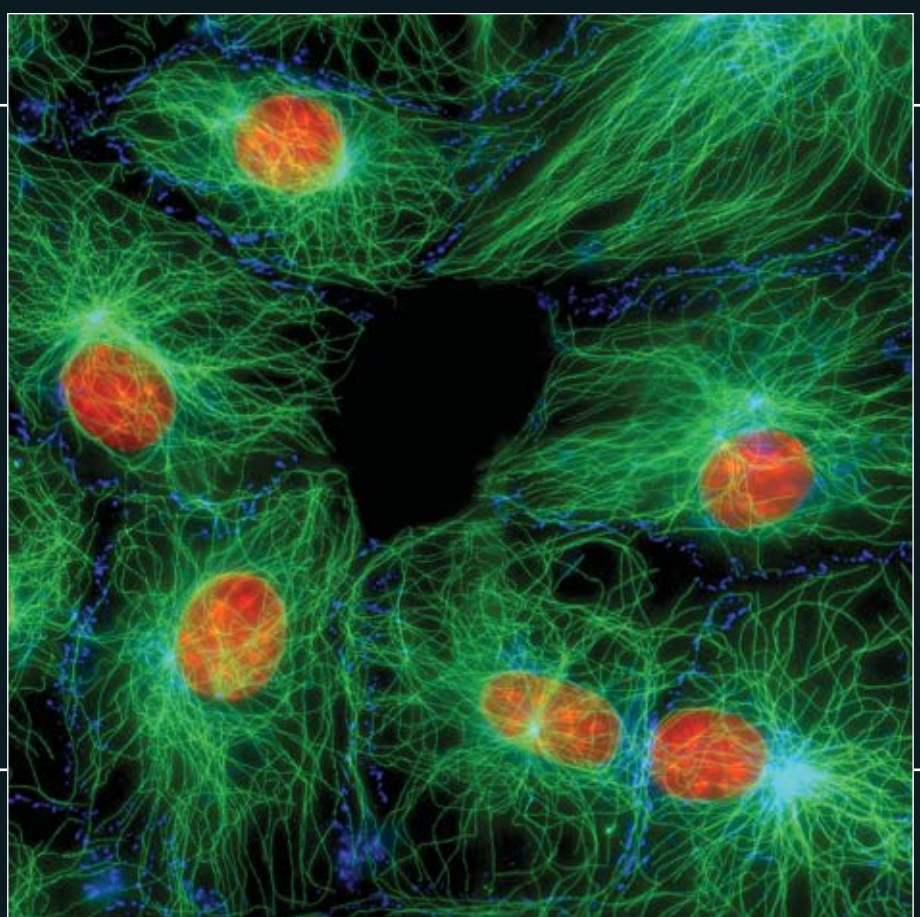
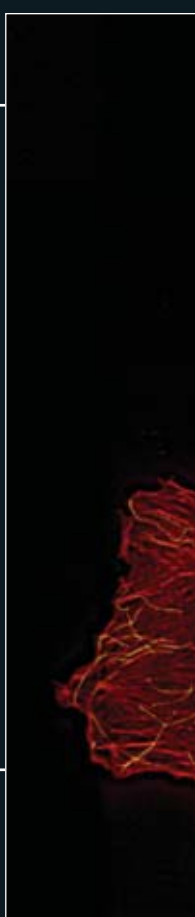
FIN OF FISH AND BONE OF GOAT: These images show two views of the dense tissue that gives vertebrates their structure. Shamuel Silberman of Ramat Gan, Israel, magnified the bones of a small fish's fin 100-fold into a dappled autumnal scene (*right*) (fiber-optic illumination). Mark Lloyd and Noel Clark of the Moffitt Cancer Center in Tampa, Fla., looked four times closer at goat bone for clues about how minerals accrue as bones form (*far right*) (widefield microscopy).





MICROTUBULES in a wounded layer of serum-starved fibroblast cells (*right*), imaged by Jan Schmoranzer of Columbia University, behave abnormally. The 20-nanometer-wide green filaments, which would normally orient toward the hole, fail to do so here (widefield). The yellow microtubules in the 138-μm-wide field imaged by U. Serdar Tulu of Duke University (*far right*) are forming around blue-colored chromosomes during the interphase stage of cell division (spinning-disk confocal microscopy).

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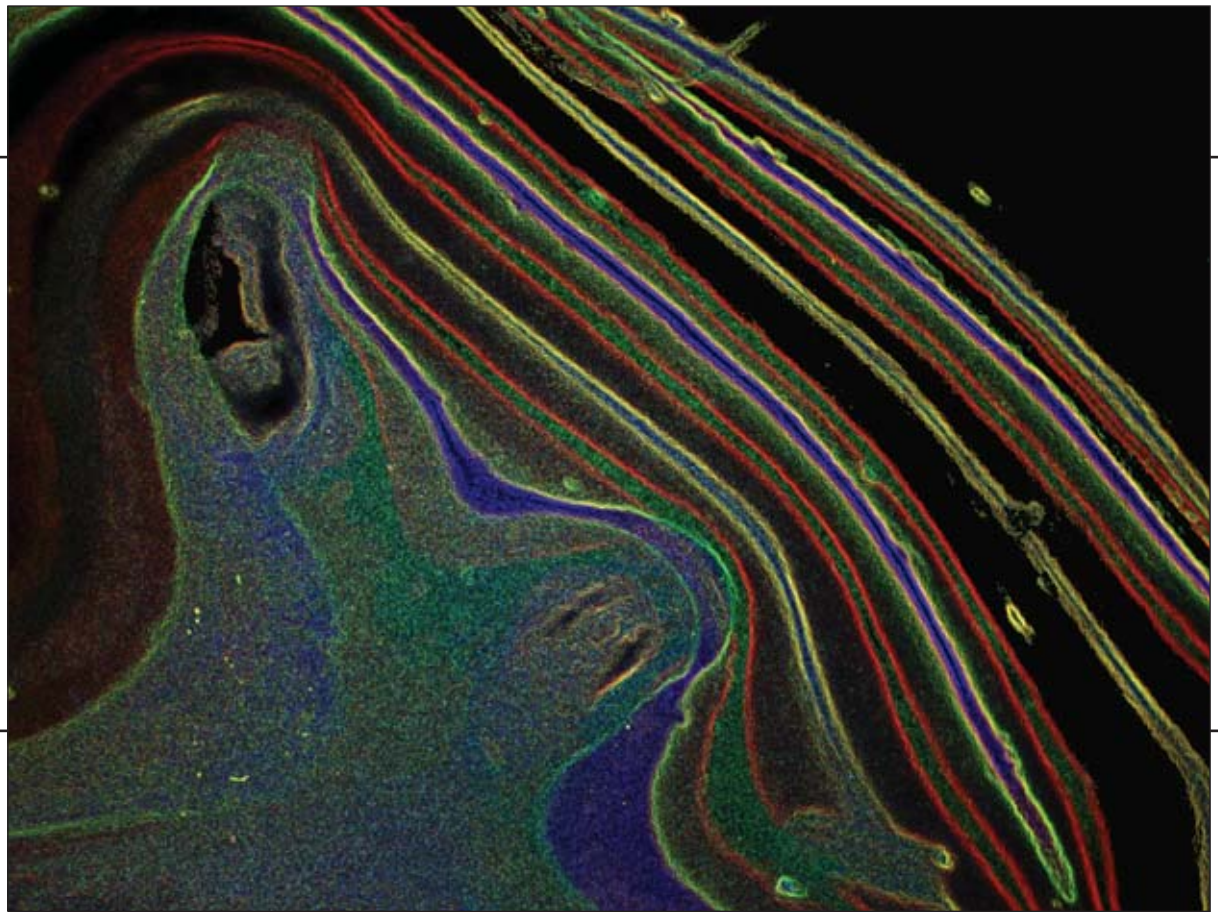

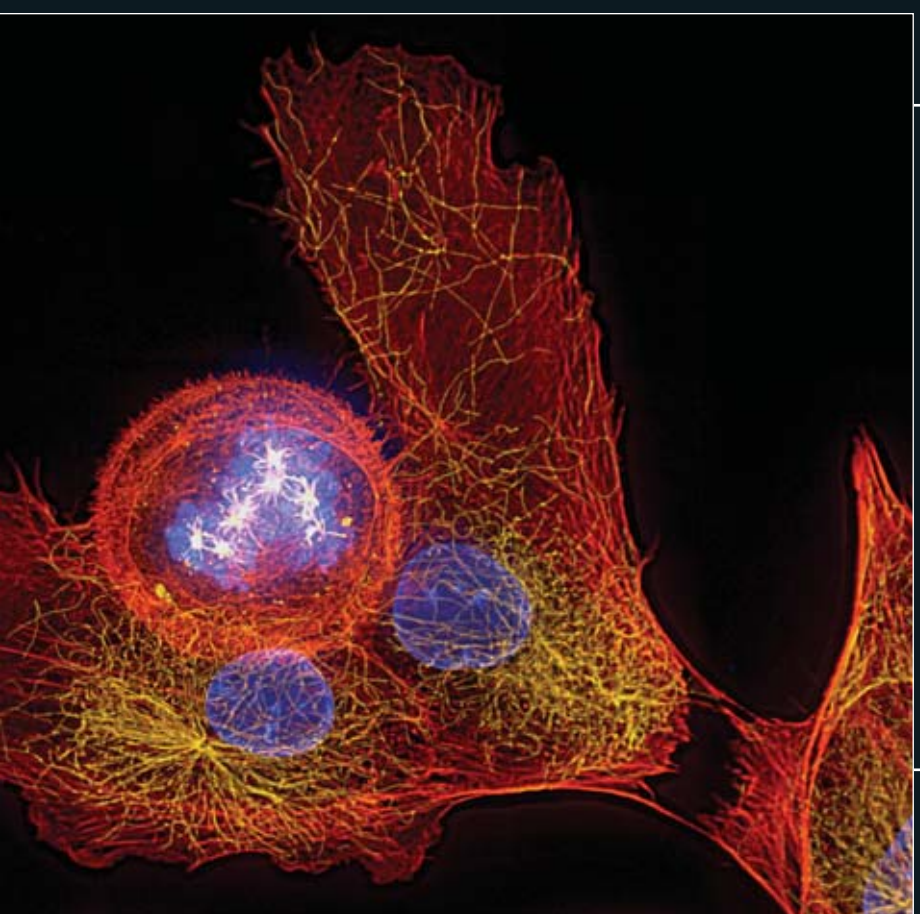

The images on these pages bring to mind a story from physicist Richard Feynman's The Pleasure of Finding Things Out. *A friend of his had claimed that a scientist could not see the beauty of a flower as well as an artist and that, furthermore, the scientist turned the flower into a dull thing by taking it all apart. Feynman disagreed, saying:*

"I think he's kind of nutty. First of all, the beauty that he sees is available to other people and to me, too, I believe, although I might not be quite as refined aesthetically as he is; but I can appreciate the beauty of a flower . . . I can imagine the cells in there, the complicated actions inside which also have a beauty. I mean it's not just beauty at this dimension of one centimeter, there is also beauty at a smaller dimension, the inner structure. Also the processes, the fact that the colors in the flower evolved in order to attract insects to pollinate it is interesting—it means that insects can see the color. It adds a question: Does this aesthetic sense also exist in the lower forms? Why is it aesthetic? All kinds of interesting questions which shows that science knowledge only adds to the excitement and mystery and the awe of a flower." ■

REPRINTED FROM *THE PLEASURE OF FINDING THINGS OUT*, BY RICHARD P. FEYNMAN. COPYRIGHT 2005 BY BASIC BOOKS

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DIET ADVICE

KEY CONCEPTS

- Genetic testing may eventually form the basis for suggestions about diet and exercise regimens tailored individually to each patient.
- Although the science has not advanced far enough to make such recommendations, Internet-based companies already market gene tests and tell patients how to eat and exercise, while selling overpriced vitamins.
- Much of the advice is no better than what can be obtained by visiting a physician or reading a newspaper's health column.

—The Editors

When President Bill Clinton stood in the East Room of the White House on June 26, 2000, and hailed the completion of the Human Genome Project, calling its results "the most important, most wondrous map ever produced by humankind," he was not looking to inaugurate an era of high-tech snake oil sales. Yet less than a decade later Web-based purveyors of genetic tests and dietary supplements are hawking nutritional genetics, or nutrigenetics, with claims that it can look at an individual's genetic information to figure out what that person should eat to promote stronger bones, shinier hair and other trappings of good health. So far, though, hyperbole has outpaced promise. This nascent field provides a cautionary tale of how commerce often races ahead of science: the commercialization of gene detection technology has occurred before scientists have developed an adequate understanding of how particular genes contribute to health and disease.

Information derived from sequencing the DNA code in every human chromosome is gradually enabling scientists to create tests and treatments that have the potential to prevent, diagnose, ameliorate and perhaps even cure disease. It is also paving the way for "personalized medicine," which is based on the recognition that genetic differences among individuals can explain why one person's body reacts differently than another's to food, drugs, sun, exercise, allergens or other stimuli. In an ideal world, a genetic test would reveal which medication or other therapy would work best and produce the fewest side effects in a given individual. And investigators are now beginning to create such tests. One milestone occurred this past summer, when the Food and Drug Administration approved the first genetic test to help a patient gauge the best dosage for a blood-thinning drug called warfarin. The test is certain to be followed by scores of others that attempt to better match drug to patient.

PHOTOILLUSTRATION BY AARON GOODMAN

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Internet marketers claim that a genetic test can give you a personalized diet. Are they advertising cutting-edge science or a high-tech horoscope?

By Laura Hercher

FROM DNA?

As part of this trend, specialists in nutrition and genetics at leading universities have begun to investigate how a person's health may be influenced by the way that food can switch particular genes on or off, or how diet can make up for some physiological deficiency caused by certain gene variants. The underlying idea is not new. A genetic test for a diet-related metabolic disorder, phenylketonuria, dates back to 1963—and the notion that food can have medicinal properties originates with Hippocrates. But the Human Genome Project has expanded the prospects for investigating links between diet and genetic predisposition to disease. Genetic analyses could well lead to truly effective personalized dietary recommendations, but that day has not yet arrived.

The Problem in Microcosm

A gene that sits at one end of chromosome 1, the longest in the human genome, illustrates both the promise of and the caveats about nutrigenetics. It encodes an enzyme called methylene hydrofolate reductase (MTHFR) that initiates the breakdown of homocysteine, an amino acid that, when elevated, has been found in some studies to be tied to increased risk of heart disease or stroke. Other studies, however, have failed to find such a link.

The exact sequence of DNA code that makes up a gene can differ slightly from person to person—and one version of the gene for MTHFR produces an enzyme with relatively low activity, which leads to a buildup of homocysteine. A person with this particular form of the gene can lower homocysteine levels by consuming certain B vitamins through supplements or food and, in theory, diminish cardiovascular risk.

The research that revealed the homocysteine-elevating role of the gene variant encoding the weakly active version of MTHFR is the kind of science that might one day produce genuine diet-related personalized medicine: routine use of an MTHFR test and, for those harboring the variant, a recommendation from medical authori-

JIMMY COHRSSEN Getty Images (orange)

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Commercial nutrigenetic testing cannot yet provide consumers with better information than routine entreaties to eat right and get plenty of exercise.

ties to compensate for it by consuming extra vitamin B in foods such as spinach or beans or by taking a supplement. But making that kind of suggestion today would be premature, because no one has yet shown that such action would lower the risk of cardiovascular disease. In fact, five large-scale clinical trials have found that vitamin B supplementation, although it does lower homocysteine levels, does not decrease the incidence of heart disease or stroke—findings that raise questions about the connection between homocysteine and cardiovascular disease. After the most recent trial, reported in the September 12 *Journal of the American Medical Association,* an editorial concluded that insufficient evidence exists to recommend routine use of vitamin supplements that lower homocysteine.

Yet scientific doubt about homocysteine as a risk factor for cardiovascular disease has not stopped the marketing of tests for MTHFR. Nor has it forestalled promotion of tests for other gene variants, many of which are surrounded by similar uncertainties.

Test Results: Eat Your Spinach

Even before the ink had dried on the first draft of the Human Genome Project, the prospect of selling nutrigenetics information had attracted entrepreneurs. During the same month that President Clinton announced the inauguration of a new genetic era, Sciona, a small British start-up company, began selling the first gene tests promoted with a promise to provide individual dietary guidance based on the results. Other companies, including Genelex, Genova Diagnostics and Suracell, have also entered the nutrigenetics market with their own panels of tests.

A Sciona offering called Cellf can be obtained by logging on to a Web site and making the $269 purchase with a credit card. A kit sent by the mail instructs the purchaser to fill out a questionnaire about age, weight, smoking status and other lifestyle-related questions. The kit also directs the person to collect a DNA sample by swabbing the inside of the cheek. The questionnaire and sample are sent back to the company, which returns a genetic analysis three weeks later. The report describes which variant of MTHFR, as well as of 18 other unrelated genes, the test subject carries and analyzes what that information suggests about how the person should eat and exercise.

Demand for these tests seems to be growing—one unidentified company reportedly sold more than 35,000 nutrigenetic tests between 2003 and 2006. Investors have also shown interest. Prominent venture-capital firms have invested millions of dollars in Sciona, the market leader, under the assumption that lifestyle DNA tests represent the future of genetics.

Governments and consumer groups have looked less kindly on nutrigenetics. After they brought pressure to bear on Sciona, the company withdrew its products from the Body Shop in the U.K. and eventually decided to move to the U.S. "We were concerned about the fact that they were overselling their capabilities," explains Helena Kennedy, who chairs the Human Genetics Commission, which advises the British government on new developments in genetics and those developments' likely impact on society. "We suggested to Sciona that if they persisted we would inquire in a public forum into what they were offering."

Likewise prompted by concerns over the direct marketing of these tests, the U.S. Government Accountability Office (GAO) ran a small sting operation in the spring of 2006. Investigators created fictitious consumer profiles by submitting questionnaires and DNA samples to four unidentified Web-based testing sites.

In total, the investigators purchased separate tests for 14 bogus applicants using 12 DNA samples from the nine-month-old daughter of Gregory Kutz, the forensic auditor who led the probe, and two more from an unrelated 48-year-old man who also works for the investigative arm of Congress. Each questionnaire submitted with the samples described adult men and women of different ages, weights and lifestyles [*see box on opposite page*].

When two samples of Kutz's daughter's DNA were submitted to one of the companies, they generated contradictory results: a gene tested in one sample revealed a particular variant, and, surprisingly, the same gene tested in the other sample did not. But the GAO did find some validation of the testing. An additional attempt to trick the testers with either blank samples or DNA from a dog or cat failed.

The audit agency also found deep fault with how the information was used. In July 2006 Kutz testified before a congressional committee that common practices by nutrigenetics companies "mislead consumers." The reports on fictitious consumers included assessments of heart and bone health, antioxidant activity, and susceptibility to inflammation and insulin resistance that the GAO deemed could not have been determined from the genetic results and questionnaires. The investigators called the

[THE AUTHOR]

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DOUGLAS HERCHER (*Hercher*); KEVIN SUMMERS *Getty Images (broccoli)*

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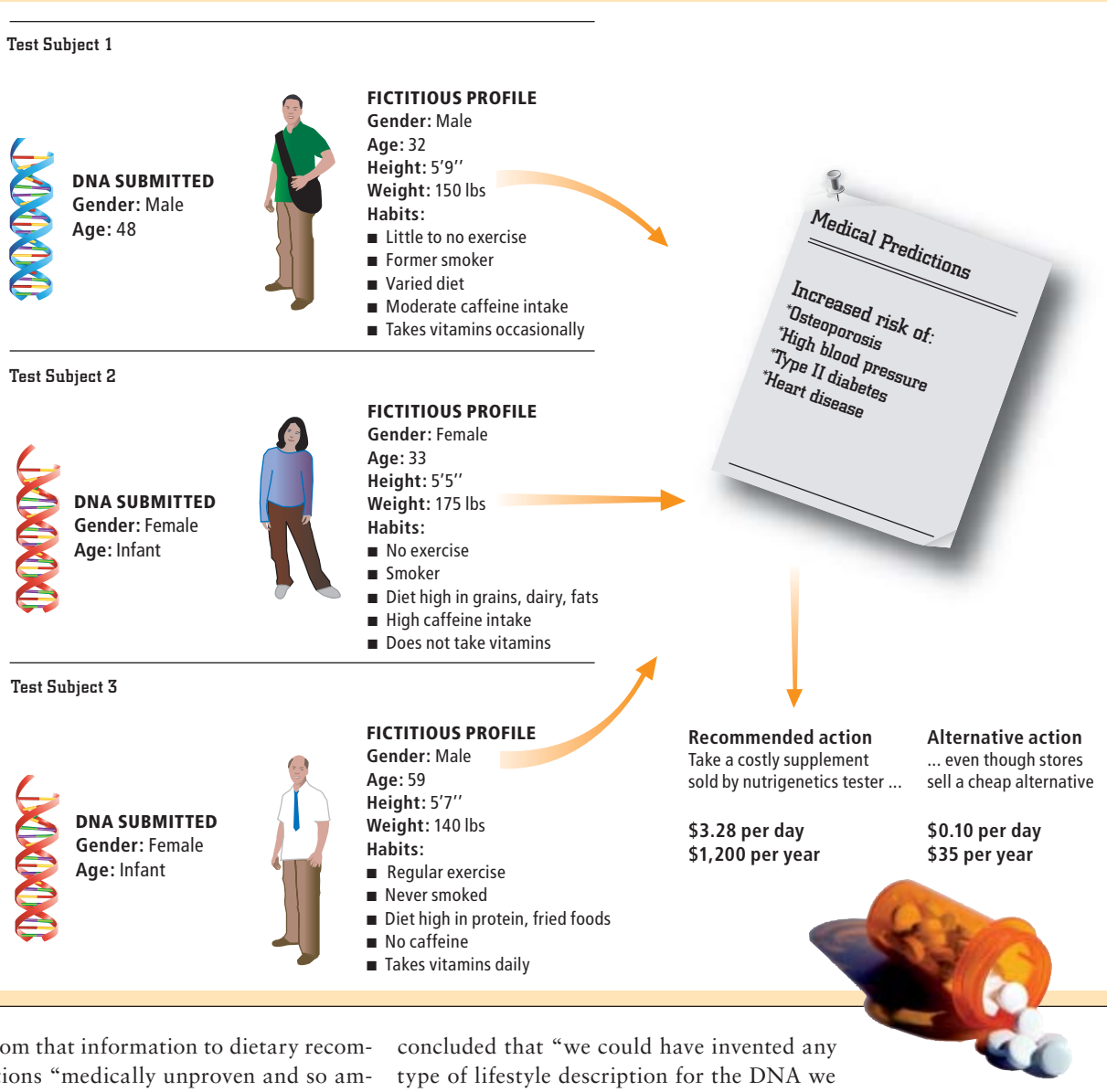
[GOVERNMENT STING]

ARE INTERNET NUTRIGENETIC TESTS VALID?

The U.S. Government Accountability Office probed the legitimacy of Internet nutrigenetics services by submitting profiles for fictitious customers (*below*), along with DNA from either a 48-year-old man for one of the samples or from an infant girl for two others. The three tests produced identical predictions, despite differences in profiles and DNA. The testing service also recommended its own multivitamin to all, at a cost of $1,200 a year, despite the availability of a similar generic product for $35 annually.



ANN SANDERSON AND LOGAN PARSONS (*illustration*); ROB CASEY Getty Images (*pills*)

leaps from that information to dietary recommendations "medically unproven and so ambiguous that they do not provide meaningful information to consumers."

The personalized reports alternated between what the GAO called predictions that "could apply to any human that submitted DNA" and advice based entirely on the lifestyle questionnaire. No matter what DNA sample accompanied the profiles, the reports exhorted self-reported fried-food junkies to change their eating habits and informed smokers to quit smoking. Nonsmokers were advised not to start. GAO investigators concluded that "we could have invented any type of lifestyle description for the DNA we submitted and the recommendations would simply echo this information."

The reports were also used to market dietary supplements. The GAO documented one company's pitch for a nutritional formula "personalized" to a customer's genetic profile. Each fictitious consumer of this Web site received an identical recommendation to buy the formula at a cost of $1,200 annually. That formulation turned out to consist of typical multivitamins available in supermarkets and drugstores for

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[NO BETTER THAN COMMON SENSE]

GENES AS NUTRITIONISTS

A friend of mine, a healthy 55-year-old New Jersey woman, took a Sciona nutrigenetic test last spring called Cellf that cost $269. I paid for the test because, as a genetic counselor, I wanted to see whether Sciona's recommendations would be helpful in planning a diet and exercise regimen. The results, based on both the gene probe and a questionnaire, arrived in a 94-page color booklet called "Your Cellf Assessment, Comprehensive Health Assessment Personalized to Your Genetic Profile." The booklet analyzed several attributes: bone health, antioxidant and detoxification activity, heart health, inflammation and insulin sensitivity. I saw no clear evidence that the advice was based on solid scientific insight into the relation between genes and diet. The booklet's bone-related admonitions follow, with an analysis of the validity of the science behind them.

- **Increase your calcium intake (from 430 to 1,300 milligrams per day)**
- **Increase your vitamin D intake (from 300 to 800 international units per day)**

Beyond parroting standard advice for a 55-year-old woman, the report failed to take into account information my friend included in her questionnaire. She reported getting 15 minutes of sun exposure three or four times a week, which would induce production of adequate vitamin D without the need for supplements. Also, even though studies support the case for taking calcium and vitamin D to prevent osteoporosis and the Food and Drug Administration allows a health claim to be made for these products, the science is still unsettled. A large 2006 study of women who take these two supplements found no clear-cut benefits.

- **Increase your intake of omega-3 fatty acids (from 1.1 to 3 grams per day)**

Research showing that omega-3 fatty acids prevent osteoporosis is scant and conflicting. A 2004 analysis by the Rand Corporation's Southern California Evidence-Based Practice Center looked at several reports and found that these compounds present in some fish and plant foods helped to improve bone mineral density in two studies and had no effect in two others.

- **Reduce your weight and increase physical activity (the goal is a body mass index under 25 and up to an hour of exercise at least five days a week)**

Weight-bearing exercise can increase bone density. But a general prescription to exercise and lose weight, if you are too heavy, applies to any health-related condition, not just to bone health, and is readily available from local newspapers, Internet health sites or your mother.

- **Keep within your goal of caffeine consumption (no more than two cups of coffee daily)**

The booklet based this recommendation in part on the finding that my friend carries a particular variant of the cellular receptor for vitamin D. At least one study has associated that variant with a higher likelihood of bone loss, albeit only in elderly women who ingest caffeinated beverages equal to more than three cups of coffee a day. My friend drinks about one cup. But the science is in flux: some studies have shown an association between caffeine and bone loss; others have not. Even without knowing the relevant gene variant, a physician might make the recommendation to moderate caffeine intake. ***—L.H.***

about $35 a year. Overall, the GAO's findings sent a clear message: commercial nutrigenetic testing cannot yet provide consumers with better information than routine entreaties to eat right and get plenty of exercise. And some company recommendations attempt to persuade consumers to pay more than they need to for dietary supplements that may or may not help lower disease risk.

Wanted: Good Science

The thin foundation of science that underlies these new tests may have repercussions for the broader field of genetic testing, of which nutrigenetics forms a tiny part. Some tests seek out genes of infectious agents to diagnose diseases those microbes cause. But many others are predictive. They determine not whether a patient is afflicted with an illness but whether, say, breast cancer or Huntington's disease is likely to develop, sometimes decades later. Under the best circumstances, genetic counselors guide patients thought to be at risk based on other clues (such as a family history of breast cancer) through the difficult decisions about whether to undergo a test that could have deeply upsetting results and might reveal risk for a disease having no treatment. The genetics community worries that Internet nutrigenetic tests may dampen public faith in the validity of these more legitimate tests.

University researchers in nutrigenetics continue to explore the prospects for linking genes and diet. But they confront fundamental hurdles. Genetic tests in clinical use are relatively straightforward probes for mutations or variants of usually one or a few genes proved to cause disease by their presence or absence. To be of any value, nutrigenetic analyses must go several steps further. For cardiovascular disease, diabetes, cancer and other illnesses that nutrigenetics aims to address, many genes—some known, others still to be detected—are involved, and the genes interact.

What is more, the effects of these interactions are notoriously hard to predict. Even if a multigene nutritional test can be devised, researchers have yet to discover what the information says about the steps a person should take. Whether a specific change in diet—eating cruciferous vegetables such as broccoli or calcium-rich foods such as spinach—will change someone's disease risk any more than just following the standard advice to eat plenty of fruits and vegetables remains entirely speculative.

Some unlucky people eat right and exercise

PURESTOCK/GETTY IMAGES (*milk*); RENEE COMET Getty Images (*salmon*); RUBBERBALL/GETTY IMAGES (*woman exercising*); FOOD COLLECTION/GETTY IMAGES (*coffee cup*)

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but still come down with a disease. These unfortunates may turn out to be the ones with a hardwired genetic predisposition. "On the other hand, many people with no known genetic risk factors at all do get cancer," says Caroline Lieber, director of the Human Genetics Graduate Program at Sarah Lawrence College. Telling a person that a particular gene profile lessens the likelihood of getting cancer may provide a false sense of security. "Do they give up on preventative measures like mammography and colonoscopy, which we know save lives?" Lieber asks. "Based on what evidence?"

The FDA and the Centers for Disease Control and Prevention have emphasized the absence of scientific proof that genetic tests can be used "safely or effectively" to make nutritional choices. Both institutions have echoed qualms about other forms of genetic testing marketed directly to consumers. The question of whether at-home testing requires more regulation may intensify with the advent of genetic tests for Alzheimer's, schizophrenia and other multigene diseases, which require careful interpretation by medical professionals.

In the U.S., the FDA regulates few of the 1,000 or so genetic tests on the market for safety and effectiveness. By law, the FDA must approve only tests that are sold as medical device kits to clinical laboratories for diagnosing, treating and preventing disease. Most genetic tests, including those fashioned by nutrigenetics companies, are devised by laboratories for in-house use and therefore need not be submitted for regulatory endorsement. Nutrigenetic tests also escape the regulatory umbrella for another reason: nominally, they do not diagnose disease. The GAO, however, found that the reports received from the Web-based companies contained predictions about disease predisposition—such as a greater risk of high blood pressure or osteoporosis—that could be interpreted as diagnoses.

Operating in the underregulated ether of cyberspace, nutrigenetics represents a harbinger, a test case for the genetics field, where benefit is sometimes matched by the potential for abuse. "The promises of personalized medicine cannot be delivered without independent, expert review of the tests themselves and appropriate regulatory oversight of the labs performing the tests," notes Kathy Hudson, director of the Genetics and Public Policy Center at Johns Hopkins University.

If misused, nutrigenetics can undermine the faith of a public primed to expect great things from the Human Genome Project. If it provides the impetus for credible, reliable regulation of genetic testing, however, it will promote the legitimate efforts of science and industry to turn research straw into clinical gold. ■

[BEFORE YOU BUY]

CONSUMER CAVEATS

Last year the Federal Trade Commission, which regulates fraudulent and deceptive business practices, issued a fact sheet entitled "At-Home Genetic Tests: A Healthy Dose of Skepticism." It warned anyone considering purchasing these tests that the FDA and CDC do not consider them "a suitable substitute for a traditional health care evaluation" and made these suggestions:

- Talk to your doctor or health care practitioner about whether it might provide useful information about your health, and if so, which test would be best. Make sure you understand the benefits and limits of any test before you buy it—or take it.
- Ask your doctor or a genetic counselor to help you understand your test results. Most companies that sell at-home genetic tests do not interpret the results.
- Discuss the results of your test with your doctor or health care practitioner before making dietary or other health-related decisions. Genetic test results can be complex and serious. You don't want to make any decisions based on incomplete, inaccurate or misunderstood information.
- Protect your privacy. At-home test companies may post patient test results online. If the Web site is not secure, your information may be seen by others. Before you do business with any company online, check the privacy policy to see how they may use your personal information and whether they share customer information with marketers.
- While most other home-use medical tests undergo FDA review to provide a reasonable assurance of their safety and effectiveness, no at-home genetic tests have been reviewed by the FDA, and the FDA has not evaluated the accuracy of their claims.

FEDERAL TRADE COMMISSION (*logo*); JOSE LUIS PELAEZ *Getty Images (apple)*

Internet nutrigenetic tests may dampen public faith in the validity of more legitimate genetic tests.

MORE TO EXPLORE

Genes on the Web—Direct-to-Consumer Marketing of Genetic Testing. Adam Wolfberg in *New England Journal of Medicine,* Vol. 355, No. 6, pages 543–545; August 10, 2006.

Nutrigenetic Testing: Tests Purchased from Four Web Sites Mislead Consumers. Testimony before the U.S. Senate/Special Committee on Aging, Report GAO-06-977T, Government Accountability Office, July 27, 2006. Full text available at **www.gao.gov/new.items/d06977t.pdf**

American Society of Human Genetics Statement on Direct-to-Consumer Testing in the United States in *American Journal of Human Genetics,* Vol. 81, pages 635–637; September 2007.

Science, Society and the Supermarket: The Opportunities and Challenges of Nutrigenomics. David Castle et al. Wiley Interscience, 2007.

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The Semantic Web in Action

KEY CONCEPTS

- A wide variety of online Semantic Web applications are emerging, from Vodafone Live!'s mobile phone service to Boeing's system for coordinating the work of vendors.
- Scientific researchers are developing some of the most advanced applications, including a system that pinpoints genetic causes of heart disease and another system that reveals the early stages of influenza outbreaks.
- Companies and universities, working through the World Wide Web Consortium, are developing standards that are making the Semantic Web more accessible and easy to use. *—The Editors*

Corporate applications are well under way, and consumer uses are emerging

Six years ago in this magazine, Tim Berners-Lee, James Hendler and Ora Lassila unveiled a nascent vision of the Semantic Web: a highly interconnected network of data that could be easily accessed and understood by any desktop or handheld machine. They painted a future of intelligent software agents that would head out on the World Wide Web and automatically book flights and hotels for our trips, update our medical records and give us a single, customized answer to a particular question without our having to search for information or pore through results.

They also presented the young technologies that would make this vision come true: a common language for representing data that could be understood by all kinds of software agents; ontologies—sets of statements—that translate information from disparate databases into common terms; and rules that allow software agents to reason about the information described in those terms. The data format, ontologies and reasoning software would operate like one big application on the World Wide Web, analyzing all the raw data stored in online databases as well as all the data about the text, images, video and communications the Web contained. Like the Web itself, the Semantic

SLIM FILMS

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BY :: Lee Feigenbaum, Ivan Herman, Tonya Hongsermeier, Eric Neumann and Susie Stephens

Web would grow in a grassroots fashion, only this time aided by working groups within the World Wide Web Consortium, which helps to advance the global medium.

Since then skeptics have said the Semantic Web would be too difficult for people to understand or exploit. Not so. The enabling technologies have come of age. A vibrant community of early adopters has agreed on standards that have steadily made the Semantic Web practical to use. Large companies have major projects under way that will greatly improve the efficiencies of in-house operations and of scientific research. Other firms are using the Semantic Web to enhance business-to-business interactions and to build the hidden data-processing structures, or back ends, behind new consumer services. And like an iceberg, the tip of this large body of work is emerging in direct consumer applications, too.

Just below the Surface

The Semantic Web is not different from the World Wide Web. It is an enhancement that gives the Web far greater utility. It comes to life when people immersed in a certain field or vocation, whether it be genetic research or hip-hop music, agree on common schemes for representing

se•man•tic web
[si-'man-tik 'wĕb]
—noun

A set of formats and languages that find and analyze data on the World Wide Web, allowing consumers and businesses to understand all kinds of useful online information.

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Combining Concepts

Search engines on the World Wide Web cannot provide a single answer to a broad-ranging question such as "Which television sitcoms are set in New York City?" But a new Semantic Web engine called pediax can, by analyzing different concepts (*top, in approximated form*) found on Wikipedia's seven million online pages. Pediax, which grew from the DBpedia project to extract information from Wikipedia, provides a clean result (*bottom*) that merges text and images.

information they care about. As more groups develop these taxonomies, Semantic Web tools allow them to link their schemes and translate their terms, gradually expanding the number of people and communities whose Web software can understand one another automatically.

Perhaps the most visible examples, though limited in scope, are the tagging systems that have flourished on the Web. These systems include del.icio.us, Digg and the DOI system used by publishers, as well as the sets of custom tags available on social sites such as MySpace and Flickr. In these schemes, people select common terms to describe information they find or post on certain Web sites. Those efforts, in turn, enable Web programs and browsers to find and crudely understand the tagged information—such as finding all Flickr photographs of sunrises and sunsets taken along the coast of the Pacific Ocean. Yet the tags within one system do not work on the other, even when the same term, such as "expensive," is used. As a result, these systems cannot scale up to analyze all the information on the Web.

The World Wide Web Consortium—an ad hoc organization of more than 400 companies and universities co-hosted by the Massachusetts Institute of Technology in the U.S., the European Consortium for Informatics and Mathematics in France, and Keio University in Japan—has already released the Semantic Web languages and technologies needed to cross such boundaries, and large companies are exploiting them. For example, British Telecom has built a prototype online service to help its many vendors more effectively develop new products together. Boeing is exploring the technologies to more efficiently integrate the work of partners involved in airplane design. Chevron is experimenting with ways to manage the life cycle of power plants and oil refineries. MITRE Corporation is applying Semantic Web tool kits to help the U.S. military interpret rules of engagement for convoy movements. The U.K.'s national mapping agency, Ordnance Survey, uses the Semantic Web internally to more accurately and inexpensively generate geographic maps.

Other companies are improving the back-end operations of consumer services. Vodafone Live!, a multimedia portal for accessing ring tones, games and mobile applications, is built on Semantic Web formats that enable subscribers to download content to their phones much faster than before. *Harper's Magazine* has harnessed semantic

LUCY READING-IKKANDA (*illustration*); AGILE KNOWLEDGE ENGINEERING AND SEMANTIC WEB (*screen shot*); COURTESY OF APPLE, INC. (*laptop*)

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ontologies on its Web site to present annotated timelines of current events that are automatically linked to articles about concepts related to those events. Joost, which is putting television on the Web for free, is using Semantic Web software to manage the schedules and program guides that viewers use online.

Consumers are also beginning to use the data language and ontologies directly. One example is the Friend of a Friend (FOAF) project, a decentralized social-networking system that is growing in a purely grassroots way. Enthusiasts have created a Semantic Web vocabulary for describing people's names, ages, locations, jobs and relationships to one another and for finding common interests among them. FOAF users can post information and imagery in any format they like and still seamlessly connect it all, which MySpace and Facebook cannot do because their fields are incompatible and not open to translation. More than one million individuals have already interlinked their FOAF files, including users of LiveJournal and TypePad, two popular Weblog services.

As these examples show, people are moving toward building a Semantic Web where relations can be established among any online pieces of information, whether an item is a document, photograph, tag, financial transaction, experiment result or abstract concept. The data language, called Resource Description Framework (RDF), names each item, and the relations among the items, in a way that allows computers and software to automatically interchange the information. Additional power comes from ontologies and other technologies that create, query, classify and reason about those relations [*see box on page 95*].

The Semantic Web thus permits workers in different organizations to use their own data labels instead of trying to agree industry-wide on one rigid set; it understands that term "X" in database 1 is the same as term "Y" in database 2. What is more, if any term in database 1 changes, the other databases and the data-integration process itself will still understand the new information and update themselves automatically. Finally, the Semantic Web enables the deployment of "reasoners"—software programs that can discover relations among data sources.

Just as the HTML and XML languages have made the original Web robust, the RDF language and the various ontologies based on it are maturing, and vendors are building applications based on them. IBM, Hewlett-Packard and Nokia are promoting open-source Semantic Web frameworks—common tools for crafting polished programs. Oracle's flagship commercial database, 10g, used by thousands of corporations worldwide, already supports RDF, and the upgrade, 11g, adds further Semantic Web technology. The latest versions of Adobe's popular graphics programs such as Photoshop use the same technologies to manage photographs and illustrations. Smaller vendors—among them Aduna Software, Altova, @semantics, Talis, OpenLink Software, TopQuadrant and Software AG—offer Semantic Web database programs and ontology editors that are akin to the HTML browsers and editors that facilitated the Web's vibrant growth. Semantic Web sites can now be built with virtually all of today's major computer programming languages, including Java, Perl and C++.

We are still finding our way toward the grand vision of agents automating the mundane tasks of our daily lives. But some of the most advanced progress is taking place in the life sciences and health care fields. Researchers in these disciplines face tremendous data-integration challenges at almost every stage of their work. Case studies of real systems built by these pioneers show how powerful the Semantic Web can be.

Case Study 1: Drug Discovery

The traditional model for medicinal drugs is that one size fits all. Have high blood pressure? Take atenolol. Have anxiety? Take Valium. But because each person has a unique set of genes and lives in a particular physical and emotional environment, certain individuals will respond better than others. Today, however, a greater understanding of biology and drug activity is beginning to be combined with tools that could predict which drugs—and what doses—will work for a given individual. Such predictions should make custom-tailored, or personalized, medical treatments increasingly possible.

FRIEND OF A FRIEND

Users of a grassroots, semantic social network system—Friend of a Friend—have created a vocabulary that describes the personal information they want to post and finds common interests. The network (*logo shown*) can also integrate information from isolated, commercial systems such as MySpace and Facebook. See www.foaf-project.org

[THE AUTHORS]

All five authors have participated in various projects to develop Semantic Web technologies. **Lee Feigenbaum,** formerly at IBM, is vice president of technology and standards at Cambridge Semantics, Inc. **Ivan Herman** leads the Semantic Web Activity initiative at the World Wide Web Consortium. **Tonya Hongsermeier** is corporate manager of clinical knowledge management and decision support at Partners Healthcare System. **Eric Neumann** is executive director of Clinical Semantics Group Consulting. **Susie Stephens** was principal product manager at Oracle Corporation and has recently become principal research scientist at Eli Lilly and Company.

WWW.FOAF-PROJECT.ORG

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Personalized medicine will become possible only when semantics makes medical databases smarter and easier to use.

The challenge, of course, is to somehow meld a bewildering array of data sets: all sorts of historic and current medical records about each person and all sorts of scientific reports on a number of drugs, drug tests, potential side effects and outcomes for other patients. Traditional database tools cannot handle the complexity, and manual attempts to combine the databases would be prohibitively expensive. Just maintaining the data is difficult: each time new scientific knowledge is incorporated into one data source, others linked to it must be reintegrated, one by one.

A research team at Cincinnati Children's Hospital Medical Center is leveraging semantic capabilities to find the underlying genetic causes of cardiovascular diseases. Traditionally, researchers would search for genes that behave differently in normal and diseased tissues, assuming that these genes could somehow be involved in causing the pathology. This exercise could yield tens or hundreds of suspect genes. Researchers would then have to pore through four or five databases for each one, trying to discern which genes (or the proteins they encode) have features most likely to affect the biology of the disorder—a painstaking task. In the end, investigators often cannot afford the hours, and the work falters.

The Cincinnati team, which includes a Semantic Web consultant, began by downloading into a workstation the databases that held relevant information but from different origins and in incompatible formats. These databases included Gene Ontology (containing data on genes and gene products), MeSH (focused on diseases and symptoms), Entrez Gene (gene-centered information) and OMIM (human genes and genetic disorders). The investigators translated the formats into RDF and stored the information in a Semantic Web database. They then used Protégé and Jena, freely available Semantic Web software from Stanford University and HP Labs, respectively, to integrate the knowledge.

The researchers then prioritized the hundreds of genes that might be involved with cardiac function by applying a ranking algorithm somewhat similar to the one Google uses to rank Web pages of search results. They found candidate genes that could potentially play a causative role in dilated cardiomyopathy, a weakening of the heart's pumping ability. The team instructed the software to evaluate the ranking information, as well as the genes' relations to the characteristics and symptoms of the condition and similar diseases. The software identified four genes with a strong connection to a chromosomal region implicated in dilated cardiomyopathy. The researchers are now investigating the effects of these genes' mutations as possible targets for new therapeutic treatments. They are also applying the semantic system to other cardiovascular diseases and expect to realize the same dramatic improvement in efficiency. The system could also be readily applied to other disease families.

Similarly, senior scientists at Eli Lilly are applying Semantic Web technologies to devise a complete picture of the most likely drug targets for a given disease. Semantic tools are allowing them to compile numerous incompatible biological descriptions into one unified file, greatly expediting the search for the next breakthrough drug. Pfizer is using Semantic Web technologies to mesh data sets about protein-protein interaction to reveal obscure correlations that could help identify promising medications. Researchers there are convinced that these technologies

[ANALYZING DATABASES]

Which Genes Cause Heart Disease?

Hundreds of genes could potentially contribute to heart disease. Researchers at Cincinnati Children's Hospital Medical Center are using Semantic Web tools to find the most likely culprits by analyzing numerous online databases and scientific references (*left, on screen*), revealing possible causative connections (*right, on screen*). For example, they have pinpointed suspect genes related to a chromosomal region linked to dilated cardiomyopathy, a weakening of the heart's pumping ability.

CHANDRA GUDIVADA, ANIL JEGGA, ERIC BARDES, SCOTT TABAR AND BRUCE ARONOW *Cincinnati Children's Hospital Medical Center (screen shot)*; COURTESY OF APPLE, INC. (*monitor*)

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will increase the chance for serendipitous discoveries, accelerate the speed of delivering new drugs to market and advance the industry as a whole toward personalized medicine. "This is where the Semantic Web could help us," says Giles Day, head of Pfizer's Research Technology Center informatics group in Cambridge, Mass.

In each of these cases, the Semantic Web enhances drug discovery by bringing together vast and varied data from different places. New consumer services are being built in similar fashion. For example, the British firm Garlik uses Semantic Web software to compare previously incompatible databases to alert subscribers that they might be the target of an identity thief. Garlik culls disparate personal identity information from across the Web, integrates it using common vocabularies and rules, and presents subscribers with a clear (and sometimes surprising) view of their online identity.

Case Study 2: Health Care

The health care industry confronts an equally dense thicket of information. One initiative that has been deployed since 2004 was developed at the University of Texas Health Science Center at Houston to better detect, analyze and respond to emerging public health problems. The system, called SAPPHIRE (for *s*ituational *a*wareness and *p*reparedness for *p*ublic *h*ealth *i*ncidences using *r*easoning *e*ngines), integrates a wide range of data from local health care providers, hospitals, environmental protection agencies and scientific literature. It allows health officials to assess the information through different lenses, such as tracking the spread of influenza or the treatment of HIV cases.

Every 10 minutes in the greater Houston area, SAPPHIRE receives reports on emergency room cases, descriptions of patients' self-reported symptoms, updated electronic health records, and clinicians' notes from eight hospitals that account for more than 30 percent of the region's emergency room visits. Semantic technologies integrate this information into a single view of current health conditions across the area. A key feature is an ontology that classifies unexplained illnesses that present flulike symptoms (fevers, coughs and sore throats) as potential influenza cases and automatically reports them to the Centers for Disease Control and Prevention. By automatically generating reports, SAPPHIRE has relieved nine nurses from doing such work manually, so they are available for active nursing. And it delivers reports two to

[HOW IT WORKS]

Making the Semantic Web Tick

Several formats and languages form the building blocks of the Semantic Web. They extend similar software technologies that underlie the World Wide Web itself and have been published as standards by the World Wide Web Consortium's Semantic Web Activity initiative.

:: RDF FORMAT. The most fundamental building block is Resource Description Framework (RDF), a format for defining information on the Web. Each piece of data, and any link that connects two pieces of data, is identified by a unique name called a Universal Resource Identifier, or URI. (URLs—the common Web addresses that we all use, are special forms of URIs.) In the RDF scheme, two pieces of information, and any notation indicating how they are connected, are grouped together into what is called a triple. For example, an online reference to the famous television animal "Flipper," a reference to the relationship "is a," and a reference to the concept of "dolphin" could be joined in the triple shown below.

< uri for **Flipper** > < uri for **Is A** > < uri for **Dolphin** >

URIs can be agreed on by standards organizations or communities or assigned by individuals. The relation "is a" is so generally useful, for example, that the consortium has published a standard URI to represent it. The URI "http://en.wikipedia.org/wiki/Dolphin" could be used by anyone working in RDF to represent the concept of dolphin. In this way, different people working with different sets of information can nonetheless share their data about dolphins and television animals. And people everywhere can merge knowledge bases on large scales.

:: ONTOLOGY LANGUAGES. Individuals or groups may want to define terms and data they frequently use, as well as the relations among those items. This set of definitions is called an ontology. Ontologies can be very complex (with thousands of terms) or very simple. Web Ontology Language (known as OWL) is one standard that can be used to define ontologies so that they are compatible with and can be understood by RDF.

:: INFERENCE ENGINES. Ontologies can be imagined as operating one level above RDF. Inference engines operate one level above the ontologies. These software programs examine different ontologies to find new relations among terms and data in them. For example, an inference engine would examine the three RDF triples below and deduce that Flipper is a mammal. Finding relations among different sources is an important step toward revealing the "meaning" of information.

< uri for **Flipper** > < uri for **Is A** > < uri for **Dolphin** >

< uri for **Dolphin** > < uri for **Subclass Of** > < uri for **Mammal** >

< uri for **Flipper** > < uri for **Is A** > < uri for **Mammal** >

:: OTHER TECHNOLOGIES. The Web consortium is crafting inference engines as well as many other technologies. One is SPARQL, a query language that allows applications to search for specific information within RDF data. Another is GRDDL, which allows people to publish data in their traditional formats, such as HTML or XML, and specifies how these data can be translated into RDF. For more, see www.w3.org/2001/sw

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If two databases joined by the Semantic Web have different privacy criteria, the software will have to honor both sets of rules.

three days faster than before. The CDC is now helping local health departments nationwide to implement similar systems, replacing tedious, inconsistent and decades-old paper schemes.

The nimbleness of Semantic Web technologies allows SAPPHIRE to operate effectively in other contexts as well. When Hurricane Katrina evacuees poured into Houston's shelters, public health officials quickly became concerned about the possible spread of disease. Within eight hours after the shelters were opened, personnel at the University of Texas Health Science Center configured SAPPHIRE to help. They armed public health officials with small handheld computers loaded with health questionnaires. The responses from evacuees were then uploaded to the system, which integrated them with data from the shelters' emergency clinics and surveillance reports from Houston Department of Health and Human Services epidemiologists in the field. SAPPHIRE succeeded in identifying gastrointestinal, respiratory and conjunctivitis outbreaks in survivors of the disaster much sooner than would have been possible before.

SAPPHIRE's flexibility showcases an important lesson about Semantic Web systems: once they are configured for a general problem—in this case, public health reporting—they can quickly be adapted to a variety of situations within that field. Indeed, the CDC would like to roll out a single, integrated, SAPPHIRE-style illness alert system nationwide.

SAPPHIRE succeeds because it can unify information from many places, which can then be used for different goals. This same attribute is fueling FOAF's grassroots growth. By using an agreed-on Semantic Web vocabulary, the FOAF system finds common interests among friends and acquaintances, even if they do not belong to the same social-networking sites such as MySpace or Facebook. FOAF enthusiasts are also now developing semantic trust networks—white lists of trusted senders—as a way to fight e-mail spam.

Crossing Boundaries

The success of SAPPHIRE and other applications has prompted calls for more Semantic Web integration in health care. The Food and Drug Administration and the National Institutes of Health have both recently declared that a shift toward research into translating data across boundaries is necessary for improving the drug development and delivery process.

The same work will enhance the traditional computerized clinical decision support (CDS) systems that medical professionals use—knowledge bases that contain the latest wisdom on therapeutic treatments. Each hospital, physicians' network and insurance company has had to custom-design its own system, and all of them are struggling mightily to stay current. Every time an advance is made about diagnoses, clinical procedures or drug safety—which is often—administrators must rework their systems. The personnel time required is usually far greater than most of these organizations can afford. Furthermore, because the custom systems are frequently incompatible, making industry-wide insights or deciphering best practices is slow and cumbersome. What is more, "we are investigating Semantic Web technologies because traditional approaches for data integration, knowledge management and decision support

[UNIFYING INFORMATION]

Is a Flu Outbreak Under Way?

Public health officials take longer than they would like to recognize new disease outbreaks, because they must manually compare disparate reports in incompatible formats from many hospitals and doctors' offices. Researchers at the University of Texas Health Science Center have built a Semantic Web system that quickly and automatically tracks and analyzes these online data across the Houston area. It presents officials with clear trends, such as the incidence of flu symptoms across different age groups over time (*center, on screen*); a sharp rise would indicate early signs of outbreaks.

COURTESY OF THE CENTER FOR BIOSECURITY AND PUBLIC HEALTH INFORMATICS RESEARCH, UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON (*screen shot*); COURTESY OF DELL, INC. (*laptop*)

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will not scale to what is needed for personalized medicine," says John Glaser, chief information officer at Partners HealthCare System in Boston.

To remedy this situation, Agfa HealthCare has constructed a prototype CDS system based on Semantic Web technologies. When a person inputs a change into one part of a system, records that should be altered in other parts of the system or in the systems of another institution are automatically updated. For example, Agfa's prototype transforms standard radiology protocols into Semantic Web notation and integrates them with other common knowledge bases, such as clinical guidelines from medical societies. Institutions can maintain their own internally standardized content, yet end users such as hospitals can readily integrate new content, greatly reducing the labor hours required.

As systems such as Agfa's are implemented across the health care network, medical knowledge bases will become smarter, easier and less expensive to use. Imagine a patient who is prone to blood clots and has a genetic mutation that, according to current medical literature, will respond well to a new anticlotting medication. Over the ensuing months, however, new studies show that particular variants of this mutation actually cause that same drug to increase clotting. This patient's clinician must be notified to change the therapy for anyone with this variant. How could notifications such as this be effectively carried out given that thousands of genes are involved in hundreds of diseases across millions of patients? Meeting this challenge will not be possible without robust semantic approaches.

Daily Life, Too

The same Semantic Web technologies that are transforming drug discovery and health care are being applied to more general situations. One example is Science Commons, which helps researchers openly post data on the Web. The nonprofit organization provides Semantic Web tools for attaching legally binding copyright and licensing information to those data. This capability allows a scientist, for example, to instruct a software applet to go find information about a particular gene—but only information that comes with a free license.

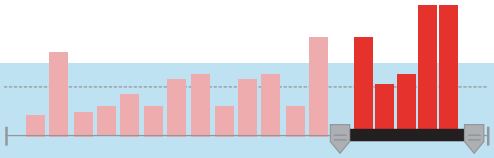
DBpedia is an effort to smartly link information within Wikipedia's seven million articles. This project will allow Web surfers to perform detailed searches of Wikipedia's content that are impossible today, such as, "Find me all the films nominated for a Best Picture Academy Award before 1990 that ran longer than three hours."

As applications develop, they will dovetail with research at the Web consortium and elsewhere aimed at fulfilling the Semantic Web vision. Reaching agreement on standards can be slow, and some skeptics wonder if a big company could overtake this work by promoting a set of proprietary semantic protocols and browsers. Perhaps. But note that numerous companies and universities are involved in the consortium's semantic working groups. They realize that if these groups can devise a few well-designed protocols that support the broadest Semantic Web possible, there will be more room in the future for any company to make money from it.

Some observers also worry that people's privacy could become compromised as more data about them from disparate sources is interlinked. But Semantic Web advocates argue that the protections are the same as those used in the nonlinked world. If two databases joined by the Semantic Web have different privacy criteria, then the software will have to honor both sets of rules or create a set that covers both. When SAPPHIRE joins patient databases, it adheres to the privacy requirements of both or it won't proceed; the nurses who had formerly performed the same mergers manually imposed the same practice.

The Semantic Web will probably operate more behind the scenes than the World Wide Web does. We won't see how it helps Eli Lilly create personalized drugs; we'll just buy them. We won't know how Vodafone makes cool ring tones so readily available, but we'll appreciate how easy they are to download. And yet, soon enough the Semantic Web will give more direct power to us, too, allowing us to go on eBay and not just say "find me the Toyota Priuses for sale" but "find me only used, red Priuses for sale for less than $14,000 by people who are within 80 miles of my house and make them an offer." Grand visions rarely progress exactly as planned, but the Semantic Web is indeed emerging and is making online information more useful than ever. ■

BLOG ANALYZER



Oracle Technology Network has demonstrated a Semantic Web site that can analyze blogs, podcasts and discussion groups to find related commentary about specific topics. It also can produce visualizations of its findings, such as tag clouds (*below*) that show whose blogs are drawing the most traffic (*larger names*) and bar charts that identify the most concentrated discussions. Project details are available at http://otnsemanticweb.oracle.com

MORE TO EXPLORE

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

Books about the Semantic Web are described at **http://esw.w3.org/topic/SwBooks**

Case studies of how companies and research groups are applying the Semantic Web can be found at **www.w3.org/2001/sw/sweo/public/UseCases**

Guides to RDF are indexed at **http://planetrdf.com/guide**, and tools to develop Semantic Web pages are available at **http://esw.w3.org/topic/SemanticWebTools**

Related blogs and RSS feeds can be accessed at **http://planetrdf.com**

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The Many Worlds of Hugh

After his now celebrated theory of multiple universes met scorn, Hugh Everett abandoned the world of academic physics. He turned to top-secret military research and led a tragic private life

BY PETER BYRNE

KEY CONCEPTS

- Fifty years ago Hugh Everett devised the many-worlds interpretation of quantum mechanics, in which quantum effects spawn countless branches of the universe with different events occurring in each.
- The theory sounds like a bizarre hypothesis, but in fact Everett inferred it from the fundamental mathematics of quantum mechanics. Nevertheless, most physicists of the time dimissed it, and he had to abridge his Ph.D. thesis on the topic to make it seem less controversial.
- Discouraged, Everett left physics and worked on military and industrial mathematics and computing. Personally, he was emotionally withdrawn and a heavy drinker.
- He died when he was just 51, not living to see the recent respect accorded his ideas by physicists.

—The Editors

Hugh Everett III was a brilliant mathematician, an iconoclastic quantum theorist and, later, a successful defense contractor with access to the nation's most sensitive military secrets. He introduced a new conception of reality to physics and influenced the course of world history at a time when nuclear Armageddon loomed large. To science-fiction aficionados, he remains a folk hero: the man who invented a quantum theory of multiple universes. To his children, he was someone else again: an emotionally unavailable father; "a lump of furniture sitting at the dining room table," cigarette in hand. He was also a chain-smoking alcoholic who died prematurely.

At least that is how his history played out in our fork of the universe. If the many-worlds theory that Everett developed when he was a student at Princeton University in the mid-1950s is correct, his life took many other turns in an unfathomable number of branching universes.

Everett's revolutionary analysis broke apart a theoretical logjam in interpreting the *how* of quantum mechanics. Although the many-worlds idea is by no means universally accepted even today, his methods in devising the theory presaged the concept of quantum decoherence—a modern explanation of why the probabilistic weirdness of quantum mechanics resolves itself into the concrete world of our experience.

Everett's work is well known in physics and philosophical circles, but the tale of its discovery and of the rest of his life is known by relatively few. Archival research by Russian historian Eugene Shikhovtsev, myself and others and interviews I conducted with the late scientist's colleagues and friends, as well as with his rock-musician son, unveil the story of a radiant intelligence extinguished all too soon by personal demons.

Ridiculous Things

Everett's scientific journey began one night in 1954, he recounted two decades later, "after a slosh or two of sherry." He and his Princeton classmate Charles Misner and a visitor named Aage Petersen (then an assistant to Niels Bohr) were thinking up "ridiculous things about the implications of quantum mechanics." During this session Everett had the basic idea behind the many-worlds theory, and in the weeks that followed he began developing it into a dissertation.

The core of the idea was to interpret what the equations of quantum mechanics represent in the real world by having the mathematics of the theory itself show the way instead of by appending interpretational hypotheses to the math. In this way, the young man challenged the physics establishment of the day to reconsider its foundational notion of what constitutes physical reality.

In pursuing this endeavor, Everett boldly tackled the notorious measurement problem in quantum mechanics, which had bedeviled physicists since the 1920s. In a nutshell, the problem arises from a contradiction between how elementary particles (such as electrons and photons) interact at the microscopic, quantum level of reality and what happens when the particles

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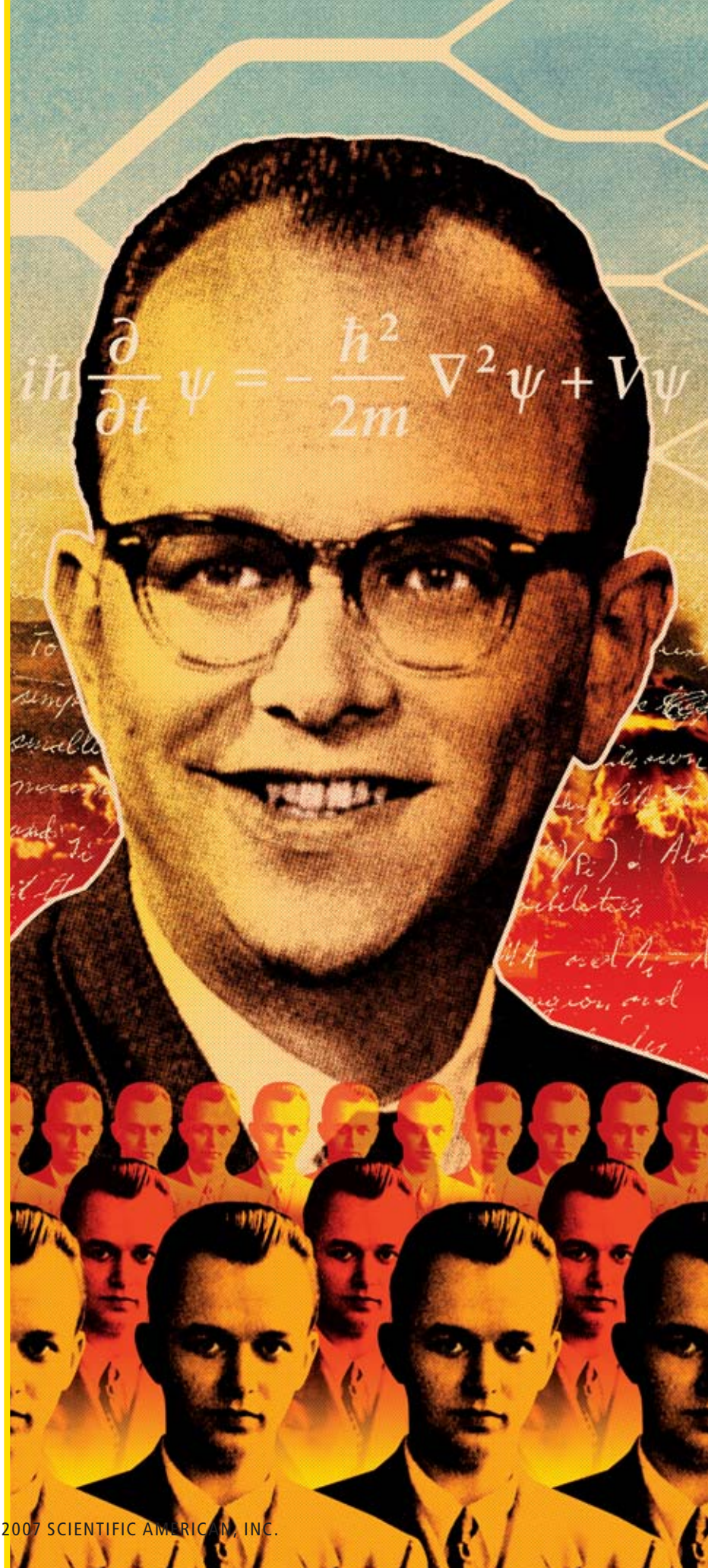
Everett



are measured from the macroscopic, classical level. In the quantum world, an elementary particle, or a collection of such particles, can exist in a superposition of two or more possible states of being. An electron, for example, can be in a superposition of different locations, velocities and orientations of its spin. Yet anytime scientists measure one of these properties with precision, they see a definite result—just one of the elements of the superposition, not a combination of them. Nor do we ever see macroscopic objects in superpositions. The measurement problem boils down to this question: How and why does the unique world of our experience emerge from the multiplicities of alternatives available in the superposed quantum world?

Physicists use mathematical entities called wave functions to represent quantum states. A wave function can be thought of as a list of all the possible configurations of a superposed quantum system, along with numbers that give the probability of each configuration's being the one, seemingly selected at random, that we will detect if we measure the system. The wave function treats each element of the superposition as equally real, if not necessarily equally probable from our point of view.

The Schrödinger equation delineates how a quantum system's wave function will change through time, an evolution that it predicts will be smooth and deterministic (that is, with no randomness). But that elegant mathematics seems to contradict what happens when humans observe a quantum system, such as an

ILLUSTRATION BY SEAN McCABE; COURTESY OF PRINCETON UNIVERSITY LIBRARY (*young Everett*); COURTESY OF EUGENE SHIKHOVTSEV AND KENNETH W. FORD (*adult Everett*); U.S. DEPARTMENT OF ENERGY/PHOTO RESEARCHERS, INC. (*mushroom cloud*); COURTESY OF THE AMERICAN INSTITUTE OF PHYSICS, NIELS BOHR LIBRARY AND ARCHIVES (*handwriting*)

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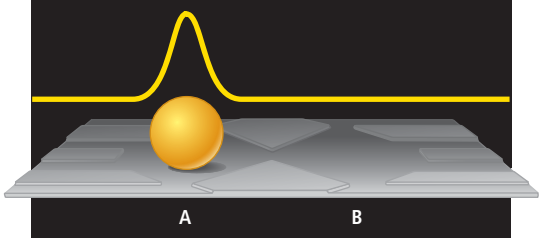
[QUANTUM MEASUREMENT]

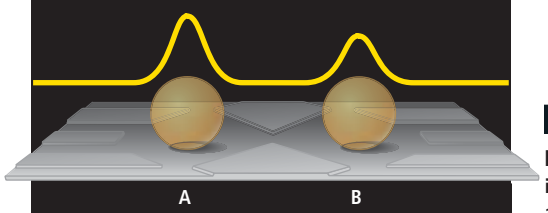
THE PROBLEM

An unresolved question in quantum mechanics is to understand fully how the quantum states of particles relate to the classical world we see around us.

Quantum mechanics represents the states of particles by mathematical entities called wave functions. For example, a wave function representing a particle at a definite location A (such as an electron in a nanoscopic trap) will have a peak at A and be zero everywhere else.



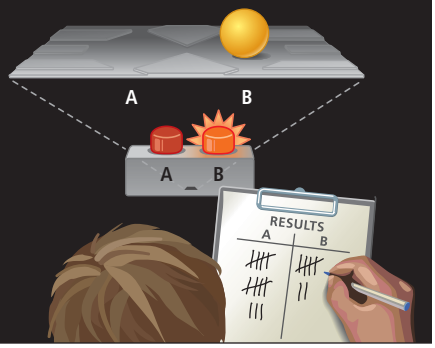
Much as ordinary waves can combine, so, too, can wave functions add together to form superpositions. Such wave functions represent particles that are in more than one alternative state at once. The amplitude of each peak relates to the probability of finding that alternative when a measurement is made.



Another way of thinking of the wave function is as a list of each alternative and its amplitude.

Position	Amplitude	Probability
A	0.8	64%
B	0.6	36%

But if an apparatus measures a particle in such a superposition, it produces a specific result—A or B, seemingly at random—not a combination of both, and the particle ceases to be in the superposition. Nor do we ever see macroscopic objects such as baseballs in superpositions.



> "The Copenhagen Interpretation is hopelessly incomplete ... as well as a philosophic monstrosity ..."
> —*Hugh Everett*

[THE AUTHOR]

Peter Byrne (www.peterbyrne.info) is an investigative journalist and science writer based in northern California. He is writing a full-length biography of Hugh Everett. Byrne acknowledges a debt to Eugene Shikhovtsev of Kostromo, Russia, who was the first historian to study the life of Everett and who generously shared his research material; to the American Institute of Physics for financial support; to George E. Pugh and Kenneth Ford for their assistance; and to the physicists who reviewed the science in this article: Stephen Shenker, Leonard Susskind, David Deutsch, Wojciech H. Zurek, James B. Hartle, Cecile DeWitt-Morette and Max Tegmark.

electron, with a scientific instrument (which itself may be regarded as a quantum-mechanical system). For at the moment of measurement, the wave function describing the superposition of alternatives appears to collapse into one member of the superposition, thereby interrupting the smooth evolution of the wave function and introducing discontinuity. A single measurement outcome emerges, banishing all the other possibilities from classically described reality. Which alternative is produced at the moment of measurement appears to be arbitrary; its selection does not evolve logically from the information-packed wave function of the electron before measurement. Nor does the mathematics of collapse emerge from the seamless flow of the Schrödinger equation. In fact, collapse has to be added as a postulate, as an additional process that seems to violate the equation.

Many of the founders of quantum mechanics, notably Bohr, Werner Heisenberg and John von Neumann, agreed on an interpretation of quantum mechanics—known as the Copenhagen interpretation—to deal with the measurement problem. This model of reality postulates that the mechanics of the quantum world reduce to, and only find meaning in terms of, classically observable phenomena—not the reverse.

This approach privileges the external observer, placing that observer in a classical realm that is distinct from the quantum realm of the object observed. Though unable to explain the nature of the boundary between the quantum and classical realms, the Copenhagenists nonetheless used quantum mechanics with great technical success. Entire generations of physicists were taught that the equations of quantum mechanics work only in one part of reality, the microscopic, while ceasing to be relevant in another, the macroscopic. It is all that most physicists ever need.

Universal Wave Function

In stark contrast, Everett addressed the measurement problem by merging the microscopic and macroscopic worlds. He made the observer an integral part of the system observed, introducing a universal wave function that links observers and objects as parts of a single quantum system. He described the macroscopic world quantum mechanically and thought of large objects as existing in quantum superpositions as well. Breaking with Bohr and Heisenberg, he dispensed with the need for the discontinuity of a wave-function collapse.

Everett's radical new idea was to ask, What

R. V. SCHEIDE (*Byrne*); JEN CHRISTIANSEN (*illustration*)

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if the continuous evolution of a wave function is not interrupted by acts of measurement? What if the Schrödinger equation always applies and applies to everything—objects and observers alike? What if no elements of superpositions are ever banished from reality? What would such a world appear like to us?

Everett saw that under those assumptions, the wave function of an observer would, in effect, bifurcate at each interaction of the observer with a superposed object. The universal wave function would contain branches for every alternative making up the object's superposition. Each branch has its own copy of the observer, a copy that perceived one of those alternatives as the outcome. According to a fundamental mathematical property of the Schrödinger equation, once formed, the branches do not influence one another. Thus, each branch embarks on a different future, independently of the others.

Consider a person measuring a particle that is in a superposition of two states, such as an electron in a superposition of location A and location B. In one branch, the person perceives that the electron is at A. In a nearly identical branch, a copy of the person perceives that the same electron is at B. Each copy of the person perceives herself or himself as being one of a kind and sees chance as cooking up one reality from a menu of physical possibilities, even though, in the full reality, every alternative on the menu happens.

Explaining how we would perceive such a universe requires putting an observer into the picture. But the branching process happens regardless of whether a human being is present. In general, at each interaction between physical systems the total wave function of the combined systems would tend to bifurcate in this way. Today's understanding of how the branches become independent and each turn out looking like the classical reality we are accustomed to is known as decoherence theory. It is an accepted part of standard modern quantum theory, although not everyone agrees with the Everettian interpretation that all the branches represent realities that exist.

Everett was not the first physicist to criticize the Copenhagen collapse postulate as inadequate. But he broke new ground by deriving a mathematically consistent theory of a universal wave function from the equations of quantum mechanics itself. The existence of multiple universes emerged as a consequence of his theory, not a predicate. In a footnote in his thesis, Everett wrote: "From the viewpoint of the theory, all elements of a superposition (all 'branches')

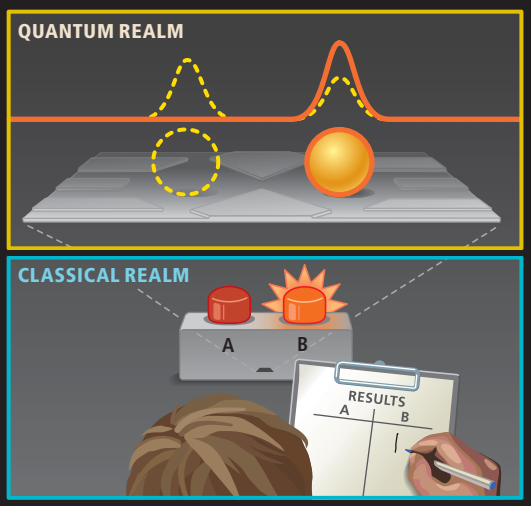
[QUANTUM MEASUREMENT]

TWO ANSWERS

The Copenhagen interpretation and Hugh Everett's many-worlds interpretation provide two strikingly different answers to the measurement problem. (There are several other hypotheses as well.)

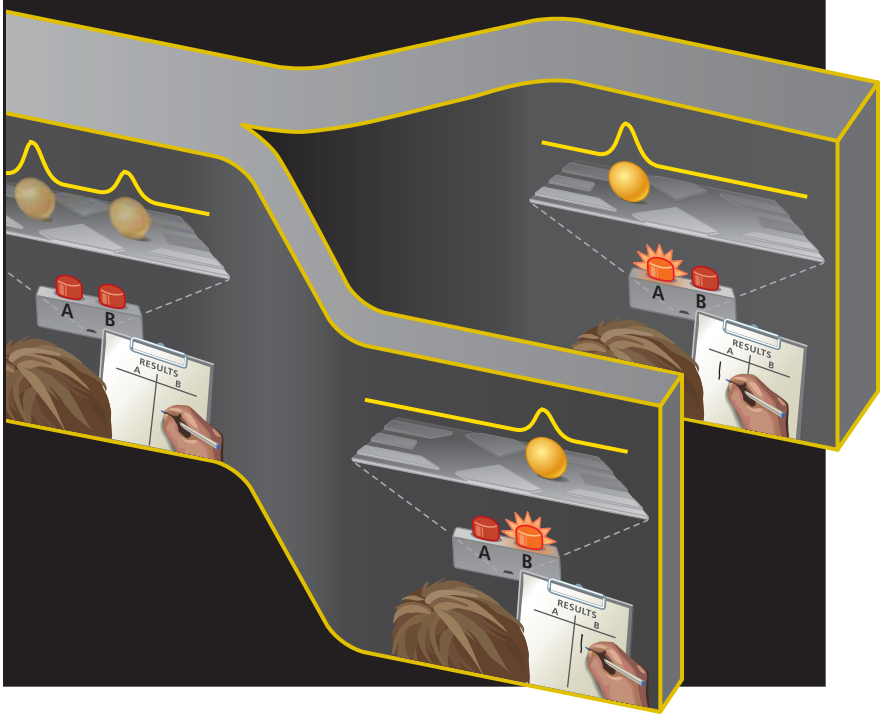
COPENHAGEN INTERPRETATION

According to Niels Bohr and others, apparatuses (and people) that make measurements reside in a classical realm that is separate from the quantum realm. When such a classical apparatus measures a superposed state, it causes the quantum wave function to collapse randomly into one of the alternatives, with all the others disappearing. The equations of quantum mechanics did not explain why such collapse should occur; it was added as a separate postulate.



MANY-WORLDS INTERPRETATION

Everett's revolutionary contribution was to analyze the measurement process with the apparatus (and people) viewed as just another quantum system, obeying the usual equations and principles of quantum mechanics. He concluded from this analysis that the end result would be a superposition of the alternative measurement outcomes and that the components of the superposition would be like separate arms of a branching universe. We do not perceive these superpositions of the macro world, because the copy of us in each branch can be aware of only what is in our branch.



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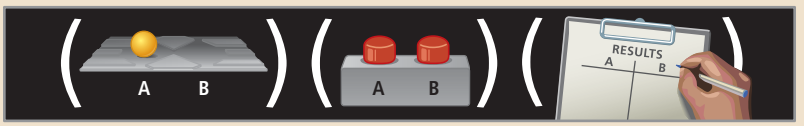
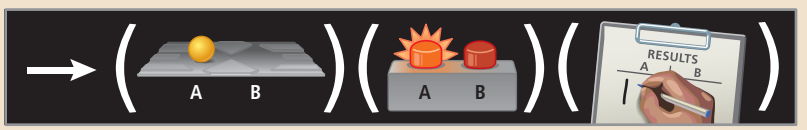
Inferring the Many Worlds

Everett supposed that everything in existence is a quantum system and obeys the Schrödinger equation. He carefully analyzed what happens when quantum measuring apparatuses and observers interact with superposed quantum objects. Thus, he considered the mathematics of a "universal wave function" that included the state of the apparatus and the observer as well as that of the object. The three states multiply together to yield the total state, as shown below:

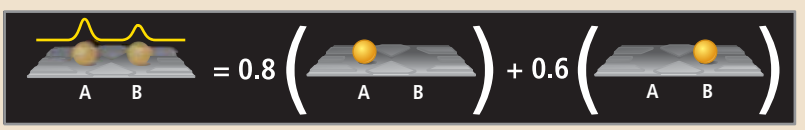


In the state depicted above, the particle is at location A with 100 percent certainty before the measurement is made. In that case (which has no puzzling superpositions), the Schrödinger equation describes how the total state evolves to a final quantum state that has no ambiguity: The interaction between particle and apparatus triggers the "A" indicator. The light travels to the observer, who sees it and forms a memory that the A indicator has flashed (*below*).



A similar completely clear-cut evolution occurs if the particle definitely began at location B. The process depicted is highly idealized, but the idealizations do not alter the conclusions.

So what happens if the particle is instead prepared in a superposition before the measurement is made? In the mathematical description, superpositions are just sums:

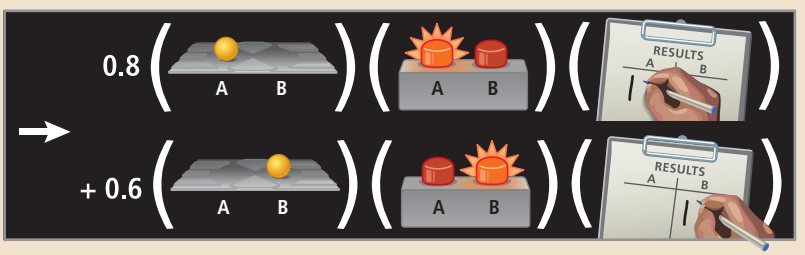


The numbers shown in this example correspond to a 64 percent likelihood of seeing the A outcome (0.64 is 0.8 squared) and a 36 percent chance of seeing the B outcome.

When the sum above is included in the initial total quantum state of the object, apparatus and observer, the result is a total state that is itself a superposition of two alternatives:

(0.8 A + 0.6 B) × Apparatus × Observer =
0.8 (A × Apparatus × Observer) + 0.6 (B × Apparatus × Observer)

Thanks to a property of the Schrödinger equation known as linearity, when this superposed total state evolves, each component (that is, the two pieces on each side of the "+" sign) evolves as it would if it were all that was present. And so the final total state is a superposition of the individual final states obtained when the particle started at a definite location:



The linearity property and a property of the states called orthogonality ensure that as time continues on, these two pieces of wave function never affect each other. A more modern analysis called decoherence theory explains that point in greater detail and depth. The "A" branch, with an observer in a state of total certainty of having seen the A light flash, proceeds on just as if it were the entirety of the wave function, as does the "B" branch. Figures that depict the universe splitting into branches with different histories represent this process. The branching is not added; it is entirely there to be found in the mathematics.

Everett further verified that the mathematics works out consistently in more complicated situations, such as those involving multiple measurements and observers. A lingering puzzle, which continues to be reanalyzed and hotly debated, is to understand in what sense branch A "occurs" 64 percent of the time and branch B only 36 percent in this model.

—Graham P. Collins, staff editor

are 'actual,' none any more 'real' than the rest."

The draft containing all these ideas provoked a remarkable behind-the-scenes struggle, uncovered about five years ago in archival research by Olival Freire, Jr., a historian of science at the Federal University of Bahia in Brazil. In the spring of 1956 Everett's academic adviser at Princeton, John Archibald Wheeler, took the draft dissertation to Copenhagen to convince the Royal Danish Academy of Sciences and Letters to publish it. He wrote to Everett that he had "three long and strong discussions about it" with Bohr and Petersen. Wheeler also shared his student's work with several other physicists at Bohr's Institute for Theoretical Physics, including Alexander W. Stern.

Splits

Wheeler's letter to Everett reported: "Your beautiful wave function formalism of course remains unshaken; but all of us feel that the real issue is the words that are to be attached to the quantities of the formalism." For one thing, Wheeler was troubled by Everett's use of "splitting" humans and cannonballs as scientific metaphors. His letter revealed the Copenhagenists' discomfort over the meaning of Everett's work. Stern dismissed Everett's theory as "theology," and Wheeler himself was reluctant to challenge Bohr. In a long, politic letter to Stern, he explicated and excused Everett's theory as an extension, not a refutation, of the prevailing interpretation of quantum mechanics:

> I think I may say that this very fine and able and independently thinking young man has gradually come to accept the present approach to the measurement problem as correct and self-consistent, despite a few traces that remain in the present thesis draft of a past dubious attitude. So, to avoid any possible misunderstanding, let me say that Everett's thesis is not meant to *question* the present approach to the measurement problem, but to accept it and *generalize* it. [Emphasis in original.]

Everett would have completely disagreed with Wheeler's description of his opinion of the Copenhagen interpretation. For example, a year later, when responding to criticisms from Bryce S. DeWitt, editor of the journal *Reviews of Modern Physics*, he wrote:

> The Copenhagen Interpretation is hopelessly incomplete because of its a priori reliance

JEN CHRISTIANSEN

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> on classical physics … as well as a philosophic monstrosity with a "reality" concept for the macroscopic world and denial of the same for the microcosm.

While Wheeler was off in Europe arguing his case, Everett was in danger of losing his student draft deferment. To avoid going to boot camp, he decided to take a research job at the Pentagon. He moved to the Washington, D.C., area and never came back to theoretical physics.

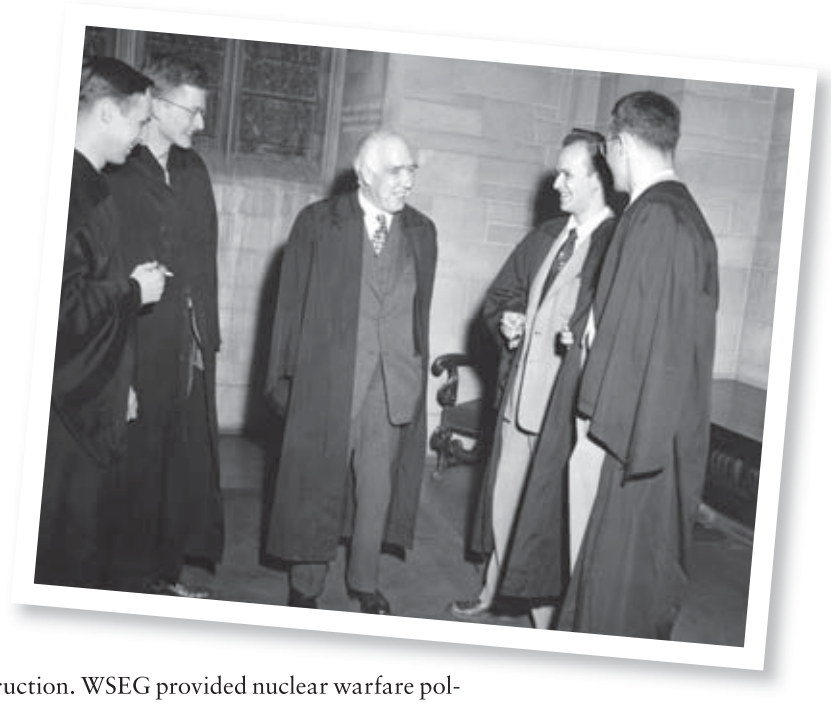
During the next year, however, he communicated long-distance with Wheeler as he reluctantly whittled down his thesis to a quarter of its original length. In April 1957 Everett's thesis committee accepted the abridged version—without the "splits." Three months later *Reviews of Modern Physics* published the shortened version, entitled "'Relative State' Formulation of Quantum Mechanics." In the same issue, a companion paper by Wheeler lauded his student's discovery.

When the paper appeared in print, it slipped into instant obscurity. Wheeler gradually distanced himself from association with Everett's theory, but he kept in touch with the theorist, encouraging him, in vain, to do more work in quantum mechanics. In an interview last year, Wheeler, then 95, commented that "[Everett] was disappointed, perhaps bitter, at the nonreaction to his theory. How I wish that I had kept up the sessions with Everett. The questions that he brought up were important."

Nuclear Military Strategies

Princeton awarded Everett his doctorate nearly a year after he had begun his first project for the Pentagon: calculating potential mortality rates from radioactive fallout in a nuclear war. He soon headed the mathematics division in the Pentagon's nearly invisible but extremely influential Weapons Systems Evaluation Group (WSEG). Everett advised high-level officials in the Eisenhower and Kennedy administrations on the best methods for selecting hydrogen bomb targets and structuring the nuclear triad of bombers, submarines and missiles for optimal punch in a nuclear strike.

In 1960 he helped write WSEG No. 50, a catalytic report that remains classified to this day. According to Everett's friend and WSEG colleague George E. Pugh, as well as historians, WSEG No. 50 rationalized and promoted military strategies that were operative for decades, including the concept of Mutually Assured Destruction. WSEG provided nuclear warfare policymakers with enough scary information about the global effects of radioactive fallout that many became convinced of the merit of waging a perpetual standoff—as opposed to, as some powerful people were advocating, launching preemptive first strikes on the Soviet Union, China and other communist countries.



NIELS BOHR (*center*) meets Everett (*near right*) at Princeton University in November 1954, the year Everett first had the many-worlds idea. Bohr never accepted the theory. Other graduate students present are (*left to right*) Charles W. Misner, Hale F. Trotter and David K. Harrison.

PHOTOGRAPH BY ALAN RICHARDS, COURTESY OF AIP EMILIO SEGRÈ VISUAL ARCHIVES

One final chapter in the struggle over Everett's theory also played out in this period. In the spring of 1959 Bohr granted Everett an interview in Copenhagen. They met several times during a six-week period but to little effect: Bohr did not shift his position, and Everett did not reenter quantum physics research. The excursion was not a complete failure, though. One afternoon, while drinking beer at the Hotel Østerport, Everett wrote out on hotel stationery an important refinement of the other mathematical tour de force for which he is renowned, the generalized Lagrange multiplier method, also known as the Everett algorithm. The method simplifies searches for optimum solutions to complex logistical problems—ranging from the deployment of nuclear weapons to just-in-time industrial production schedules to the routing of buses for maximizing the desegregation of school districts.

In 1964 Everett, Pugh and several other WSEG colleagues founded a private defense company, Lambda Corporation. Among other activities, it designed mathematical models of anti-ballistic missile systems and computerized nuclear war games that, according to Pugh, were used by the military for years. Everett became enamored of inventing applications for Bayes' theorem, a mathematical method of correlating the probabilities of future events with past experience. In 1971 Everett built a prototype Bayes-

MORE TO EXPLORE

The Many-Worlds Interpretation of Quantum Mechanics. Edited by Bryce S. DeWitt and Neill Graham. Princeton University Press, 1973.

The Fabric of Reality. David Deutsch. Penguin Books, 1997.

Biographical Sketch of Hugh Everett, III. Eugene Shikhovtsev. 2003. Online at **http://space.mit.edu/home/tegmark/everett**

Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity. Edited by John D. Barrow, Paul C. W. Davies and Charles L. Harper, Jr. Cambridge University Press, 2004.

Things the Grandchildren Should Know. Mark Everett. Little, Brown (in press).

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ian machine, a computer program that learns from experience and simplifies decision making by deducing probable outcomes, much like the human faculty of common sense. Under contract to the Pentagon, Lambda used the Bayesian method to invent techniques for tracking trajectories of incoming ballistic missiles.

In 1973 Everett left Lambda and started a data-processing company, DBS, with Lambda colleague Donald Reisler. DBS researched weapons applications but specialized in analyzing the socioeconomic effects of government affirmative action programs. When they first met, Reisler recalls, Everett "sheepishly" asked whether he had ever read his 1957 paper. "I thought for an instant and replied, 'Oh, my God, you are *that* Everett, the crazy one who wrote that insane paper,'" Reisler says. "I had read it in graduate school and chuckled, rejected it out of hand." The two became close friends but agreed not to talk about multiple universes again.

Three-Martini Lunches

Despite all these successes, Everett's life was blighted in many ways. He had a reputation for drinking, and friends say the problem seemed only to grow with time. According to Reisler, his partner usually enjoyed a three-martini lunch, sleeping it off in his office—although he still managed to be productive.

Yet his hedonism did not reflect a relaxed, playful attitude toward life. "He was not a sympathetic person," Reisler says. "He brought a cold, brutal logic to the study of things. Civil-rights entitlements made no sense to him."

John Y. Barry, a former colleague of Everett's at WSEG, also questioned his ethics. In the mid-1970s Barry convinced his employers at J. P. Morgan to hire Everett to develop a Bayesian method of predicting movement in the stock market. By several accounts, Everett succeeded—and then refused to turn the product over to J. P. Morgan. "He used us," Barry recalls. "[He was] a brilliant, innovative, slippery, untrustworthy, probably alcoholic individual."

Everett was egocentric. "Hugh liked to espouse a form of extreme solipsism," says Elaine Tsiang, a former employee at DBS. "Although he took pains to distance his [many-worlds] theory from any theory of mind or consciousness, obviously we all owed our existence relative to the world he had brought into being."

And he barely knew his children, Elizabeth and Mark.

As Everett pursued his entrepreneurial career, the world of physics was starting to take a hard look at his once ignored theory. DeWitt swung around 180 degrees and became its most devoted champion. In 1967 he wrote an article presenting the Wheeler-DeWitt equation: a universal wave function that a theory of quantum gravity should satisfy. He credited Everett for having demonstrated the need for such an approach. DeWitt and his graduate student Neill Graham then edited a book of physics papers, *The Many-Worlds Interpretation of Quantum Mechanics*, which featured the unamputated version of Everett's dissertation. The epigram "many worlds" stuck fast, popularized in the science-fiction magazine *Analog* in 1976.

Not everybody agrees, however, that the Copenhagen interpretation needs to give way. Cornell University physicist N. David Mermin maintains that the Everett interpretation treats the wave function as part of the objectively real world, whereas he sees it as merely a mathematical tool. "A wave function is a human construction," Mermin says. "Its purpose is to enable us to make sense of our macroscopic observations. My point of view is exactly the opposite of the many-worlds interpretation. Quantum mechanics is a device for enabling us to make our observations coherent, and to say that we are inside of quantum mechanics and that quantum mechanics must apply to our perceptions is inconsistent."

But many working physicists say that Everett's theory should be taken seriously.

"When I heard about Everett's interpretation in the late 1970s," says Stephen Shenker, a theoretical physicist at Stanford University, "I thought it was kind of crazy. Now most of the people I know that think about string theory and quantum cosmology think about something along an Everett-style interpretation. And because of recent developments in quantum computation, these questions are no longer academic."

One of the pioneers of decoherence, Wojciech H. Zurek, a fellow at Los Alamos National Laboratory, comments that "Everett's accomplishment was to insist that quantum theory should be universal, that there should not be a division of the universe into something which is a priori classical and something which is a priori quantum. He gave us all a ticket to use quantum theory the way we use it now to describe measurement as a whole."

String theorist Juan Maldacena of the Institute for Advanced Study in Princeton, N.J., reflects a common attitude among his colleagues: "When I think about the Everett theory quantum

EVERETT'S TIMELINE

November 11, 1930: Born in Washington, D.C.

1943: Albert Einstein replies to a letter that the adolescent Everett sent him about an irresistible force meeting an immovable object.

Fall 1953: Enters graduate physics program at Princeton University. Studies quantum mechanics under Eugene Wigner and John Archibald Wheeler.

June 1956: Takes research job with the Pentagon's Weapons Systems Evaluation Group (WSEG).

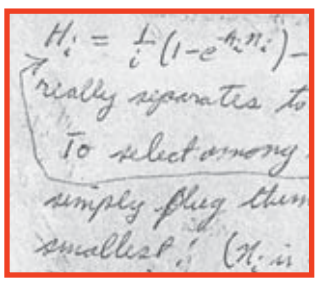
November 1956: Marries Nancy Gore.

November 1956: Appointed head of mathematics division of WSEG.

June 1957: Awarded Ph.D.

July 1957: Daughter Elizabeth born.

Spring 1959: While at the Hotel Østerport in Copenhagen, Everett devises an important refinement to a method for finding optimum solutions to complex logistical problems.



1959–1960: Helps to draft report WSEG No. 50 on nuclear military strategies.

January 1961: Personally briefs incoming Secretary of Defense Robert S. McNamara on WSEG's analysis of nuclear war-fighting options.

April 1963: Son Mark born.

1964: Everett and others from WSEG start Lambda Corporation, a defense contractor.

1973: Leaves Lambda and forms data-processing company DBS.

July 19, 1982: Dies in bed of a heart attack.

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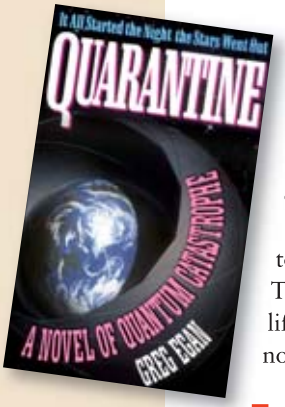
Fictional Spin-offs

Stories of parallel worlds and alternate histories have long been as common as blackberries. Here are three diverse tales that reference Everett's many-worlds theory.



- ***The Coming of the Quantum Cats*, by Frederik Pohl (Spectra, 1986):** Copies of the characters travel back and forth across the slew of alternative timelines from which they hail.

- ***Quarantine*, by Greg Egan (HarperCollins, 1992):** Quantum superpositions—and what happens when they are observed—are central to the plot and are a key to the ultimate fate of humanity.

- ***His Dark Materials* trilogy, by Philip Pullman (Knopf, 1995–2000):** This fantasy roams across several parallel worlds. In one, a physicist mentions Everett and his 1957 hypothesis; in another, two experimental theologians have proposed a many-worlds heresy.

COURTESY OF HARPERCOLLINS (*book cover*)

mechanically, it is the most reasonable thing to believe. In everyday life, I do not believe it."

In 1977 DeWitt and Wheeler invited Everett, who hated public speaking, to make a presentation on his interpretation at the University of Texas at Austin. He wore a rumpled black suit and chain-smoked throughout the seminar. David Deutsch, now at the University of Oxford and a founder of the field of quantum computation (itself inspired by Everett's theory), was there. "Everett was before his time," Deutsch says in summing up Everett's contribution. "He represents the refusal to relinquish objective explanation. A great deal of harm was done to progress in both physics and philosophy by the abdication of the original purpose of those fields: to explain the world. We got irretrievably bogged down in formalisms, and things were regarded as progress which are not explanatory, and the vacuum was filled by mysticism and religion and every kind of rubbish. Everett is important because he stood out against it."

After the Texas visit, Wheeler tried to hook Everett up with the Institute for Theoretical Physics in Santa Barbara, Calif. Everett reportedly was interested, but nothing came of the plan.

Totality of Experience

Everett died in bed on July 19, 1982. He was just 51. His son, Mark, then a teenager, remembers finding his father's lifeless body that morning. Feeling the cold body, Mark realized he had no memory of ever touching his dad before. "I did not know how to feel about the fact that my father just died," he told me. "I didn't really have any relationship with him."

Not long afterward, Mark moved to Los Angeles. He became a successful songwriter and the lead singer for a popular rock band, Eels. Many of his songs express the sadness he experienced as the son of a depressed, alcoholic, emotionally detached man. It was not until years after his father's death that Mark learned of Everett's career and accomplishments.

Mark's sister, Elizabeth, made the first of many suicide attempts in June 1982, only a month before Everett died. Mark discovered her unconscious on the bathroom floor and got her to the hospital just in time. When he returned home later that night, he recalled, his father "looked up from his newspaper and said, 'I didn't know she was that sad.'" In 1996 Elizabeth killed herself with an overdose of sleeping pills, leaving a note in her purse saying she was going to join her father in another universe.

In a 2005 song, "Things the Grandchildren Should Know," Mark wrote: "I never really understood/what it must have been like for him/living inside his head." His solipsistically inclined father would have understood that dilemma. "Once we have granted that any physical theory is essentially only a model for the world of experience," Everett concluded in the unedited version of his dissertation, "we must renounce all hope of finding anything like *the* correct theory … simply because the totality of experience is never accessible to us." ■

SCI AM

See **www.SciAm.com/ontheweb** for materials related to this article, including the 1959 Hotel Østerport note and other interpretations of quantum mechanics.

THEORY'S TIMELINE

Winter 1954–1955: Everett begins writing doctoral dissertation on quantum mechanics.

January 1956: Everett hands in completed draft thesis, "The Theory of the Universal Wave Function."

Spring 1956: Wheeler takes the thesis to Copenhagen to discuss with Niels Bohr and other leading physicists. They react negatively to it.

August 1956–March 1957: Wheeler and Everett rewrite the thesis, drastically abridging it.

April 1957: Thesis committee accepts the abridged dissertation, "'Relative State' Formulation of Quantum Mechanics."

May 1957: Bryce S. DeWitt (editor of *Reviews of Modern Physics*) insists in a letter to Wheeler that "the real world does not branch."

July 1957: *Reviews of Modern Physics* publishes abridged thesis, along with a praiseful assessment of the theory by Wheeler.

Spring 1959: Everett meets Bohr in Copenhagen, but neither budges in his position on the theory.

March 1970: Dieter Zeh publishes a seminal paper on decoherence. He credits Everett's work.

September 1970: DeWitt publishes review article in *Physics Today*, promoting Everett's theory.

1973: DeWitt and Neill Graham publish both versions of the thesis as well as other papers in a book.

December 1976: Science-fiction magazine *Analog* popularizes the theory.

July 1985: David Deutsch proposes quantum computer that could exploit Everettian parallelism.

July 2007: Fiftieth anniversary of Everett's *Reviews of Modern Physics* paper marked by a conference at the University of Oxford and on the cover of *Nature*.

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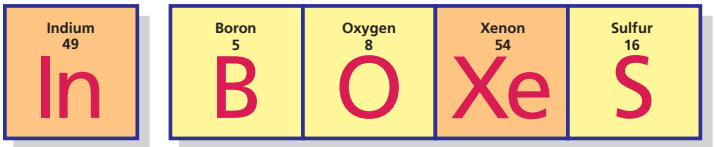

The atomic symbols on the opposite page are all you need to fill in the highlighted squares. One-letter symbols go in the yellow boxes, two-letter symbols in the orange boxes. Some appear in the grid more than once. The 12 highlighted answers relate to articles that appeared in *Scientific American* in 2007—one for each month.

By Patrick Merrell

ACROSS

1 Not retro yet
6 *Nautilus* captain
10 Applies lightly
14 Second-deepest U.S. lake
19 Chemical or free follower
20 "Bring ___!"
21 Subjects for Freud
22 Like a bump on a log
23 Standard game theory uses this label for the decision that ends up reaping a high reward in Traveler's Dilemma (**June**)
25 An eyeball subtly does this, allowing us to see (**August**)
27 Knuckle walkers
28 Edict
29 Country albums?
33 Ranch vacationers
36 Play a secondary role
41 Fertile soil
42 Sport involving moonballs
44 Back on board
46 Natural selection may have actually aided this disease to some degree (**January**)
47 Hugh Everett's "many worlds" theory predicts huge numbers of these (**December**)
50 High-pitched sound
51 Even prime
52 It's in your head
53 Longtime Elton John label
54 Horn or Canaveral
56 Go undersea
59 Ave. crossers
60 One with a burning desire, for short?
61 Inspired by these biological workhorses, chemists have now created programmable molecular building blocks (**February**)
62 Plasm prefix
64 Edison preceder
67 Scales
69 For the first time, in 2004, doctors saved an unimmunized person sick from this animal-borne killer (**April**)
73 Jawbone grinders
75 Gyroscopic toy
76 Premed course
77 Lack for 27-Across
78 In a posthuman world, this once tame animal might thrive (**July**)
80 Map boxes
84 D-Day vessels
85 It's a long story
86 Space probe that has traveled farther than any other man-made object—more than nine billion miles (**October**)
87 LAX listings
89 Remote power source?
92 Big body abutting Britain
94 "It's clear to me now"
95 Bunny boss, briefly
98 Remove sails, lines and gear
100 Article written by Hertz?
101 *Battlefield Earth* author Hubbard
103 This type of digital archive might one day supplement individual memory (**March**)
105 50 percent of the risk for addiction and obesity is ___ (**September**)
106 Venomous coiler
107 Control, as escalating costs
109 Asian belts
110 Replace old caulking
112 Big insurance co.
113 Collapse
116 Ancient Dead Sea fortress
119 Swain
120 The large amount of methane here, near Saturn, raises the possibility of life (**May**)
124 This early, rapid expansion of the universe could hold keys to unlocking a theory of everything (**November**)
130 A dwarf planet
131 Ripped
132 18 grams of water, e.g.
133 Terra ___
134 Proficiency
135 Exceeded limits
136 Stone and Iron, e.g.
137 Geyser output

DOWN

1 Duo
2 Taj Mahal site
3 Alien-seeking org.
4 Souvenir globe filler
5 Lab burners of old
6 Most amicable
7 Cultural values
8 Lavoisier's "Me?"
9 A long time ago
10 Solves, in a way
11 Chemist Pockels or dancer de Mille
12 Type of pear
13 Cool red giant
14 Sir and madame
15 One, some or all
16 ___ *the Magnificent* (classic educational film about blood)
17 A Wright brother, casually
18 Peak vacation times, for Curie
24 Peak, for Curie
26 Orderly
29 Astringent crystals once used in canning
30 Elixir
31 Hot fissure emission
32 Head of the A.M.A.?: Abbr.
33 Makeup stuff?
34 Simultaneously, with "in"
35 Watered down
37 Laceration leftover
38 Chemical endings
39 Sing sans lyrics
40 Glossary contents
43 XX-rated farm animal?
44 Amaze
45 Portends
48 Pres. appointee
49 Pie purveyor Lee
51 ® alternatives
52 Abhor
55 Mail with pretty pictures
57 Receptacles
58 Fi lead-in
60 Deep sympathy
61 Get ready for surgery
63 Orbital paths viewed obliquely, e.g.
64 Org. with bomb-sniffing dogs
65 Look lasciviously
66 Wiener schnitzel meat
68 Layer
69 Part of the hydrologic cycle
70 Pupil surrounder
71 Nth deg.
72 Comic strip leak
74 ___ He River, also known as the Yellow River
76 Brewed beverage
79 Utah's state flower
80 Altos intro
81 Reinforced hole
82 First man in space
83 Instructions part
86 Videotape format
88 Ruminant with a rack
89 Boring tool
90 1 Avril to 31 Mars
91 *Ars gratia* ___ (MGM motto)
93 Faucet
94 Magician's name ending
95 Bindle-toting nomad
96 Tennyson's Arthurian story *Geraint and* ___
97 Simple test answer
99 Cap material
102 Man-mission link
104 Martian day, to astronomers
106 Famed Texas Revolution battle site
107 Hit from behind
108 Girls in trees?
111 Explosive mixture
112 Stick
114 Large sewer pipe
115 Smoker's output
117 They used to travel at Mach speeds
118 Per person
119 Gallbladder stuff
120 People wait to get them
121 Converse
122 Rapa ___ (Easter Island)
123 Cardinals, on a scoreboard
124 Vegetative state
125 Noxious urban gases
126 Café au ___
127 Toroidal car part
128 Tumor suffix
129 1960s war zone, briefly

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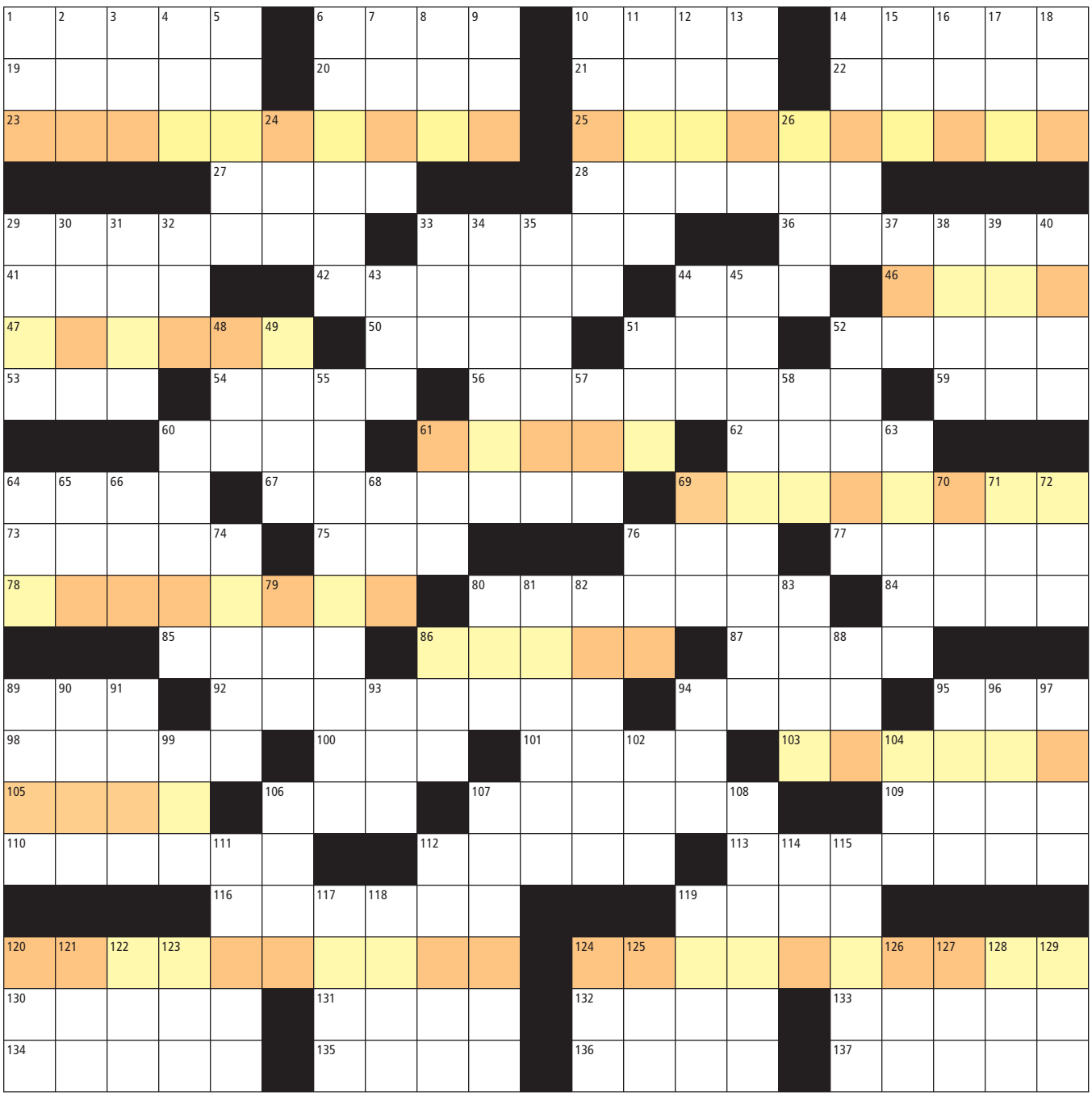
Ag	Al	At	B	C	Ca	Ce	Co	Er	Es	F	Ge	He	Ho	I	In	Ir	La		
Mo	N	Ne	Ni	O	P	Pr	Ra	Re	S	Se	Sm	Ta	Te	Ti	Tl	U	V	Y	



JERRY ENGLISH

[THE AUTHOR]

Patrick Merrell is a professional puzzlemaker, cartoonist and graphic designer. He is the author of many books, including his latest, *Coffee Time,* an extensively researched compendium of coffee lore, trivia and puzzles. Merrell regularly contributes crosswords to the *New York Times* and the American Crossword Puzzle Tournament. He is also the creator of Sci-Doku (like Sudoku but with a couple of twists), available at **www.SciAm.com**. Find his Web site at **www.patrick.merrell.org**

SCI AM

Answers appear in the January 2008 issue and at **www.SciAm.com/ontheweb**

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Progress Accelerates

By Mark Fischetti

Cruise control—which keeps a vehicle at a constant speed—has been around for decades. But a recent upgrade could spark a progression of advances that might finally lead to the long-envisioned car that drives itself.

With standard cruise control, a driver sets a desired speed. The engine controller opens the throttle to accelerate the car or closes it to slow the car using engine drag. A few enhanced systems can also gently apply the brakes if the drag is insufficient—for example, when the car is heading down a steep hill.

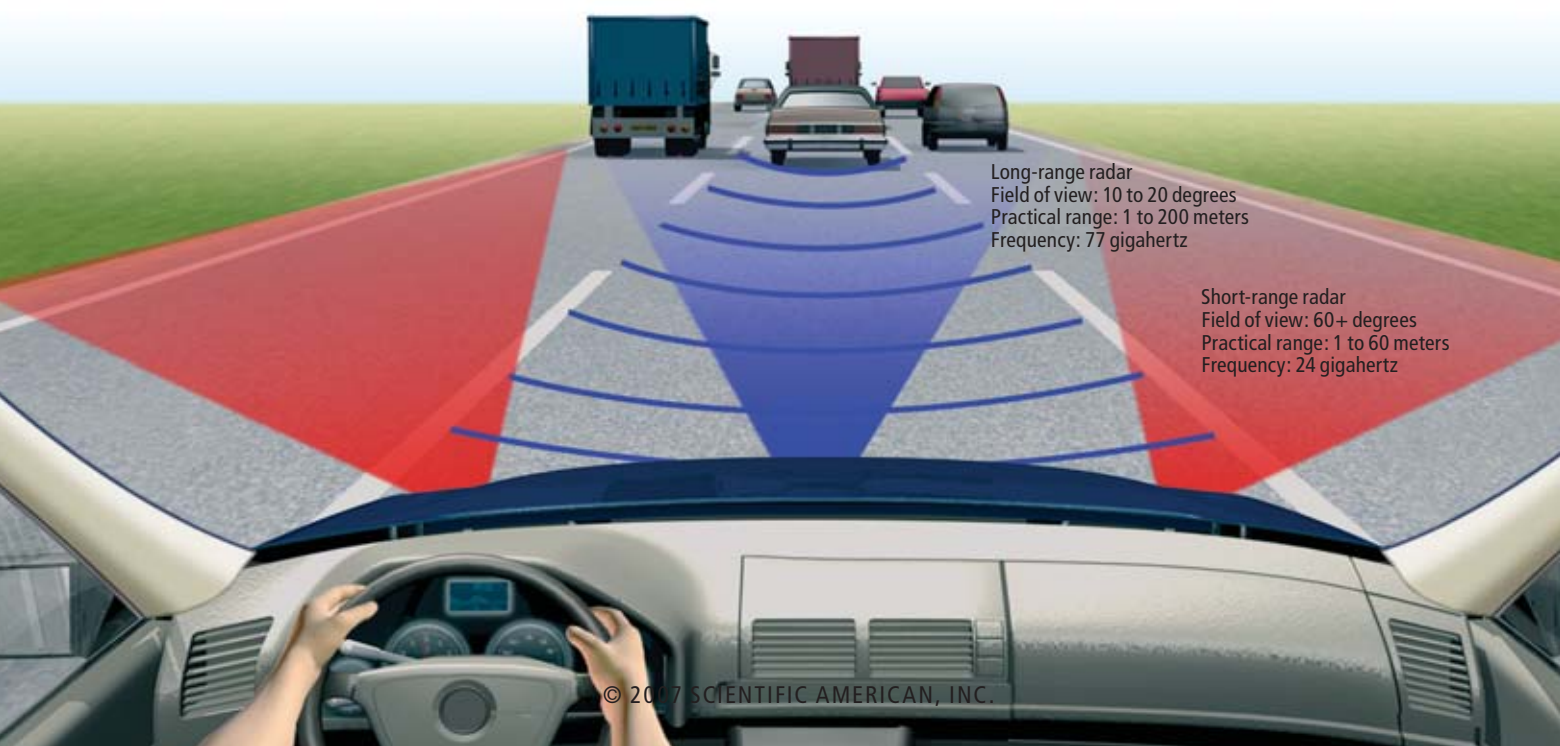
Neither system knows if the car is approaching a slower vehicle in front of it, however, forcing the driver to hit the brakes. Adaptive cruise control, now offered on certain models, uses long-range radar or lidar (*li*ght *d*etection *a*nd *r*anging) to track vehicles directly ahead [*see illustration below*]. The driver sets a speed as well as a "headway gap" from one to three seconds. If the car closes in on a vehicle ahead, the system reduces throttle—and applies the brakes, if necessary—to slow the car, then continually adjusts the speed to maintain a constant time gap between the vehicles. When the lead vehicle changes lanes or turns off the road, the system brings the car back up to the set speed. If the lead vehicle drops below a threshold speed, such as 15 miles per hour, the system deactivates and audibly warns the driver to take over.

A few manufacturers are just starting to offer next-generation "stop and go" adaptive cruise control. The system can bring the car to a stop and accelerate it again, a useful feature in traffic. With some systems if the car stops the driver must tap the accelerator or touch a button to put the car in motion again. This capability requires installation of short-range radars that can sense vehicles (as well as pedestrians) right up to and around the front bumper.

Autonomous vehicles may be next. "Adaptive cruise control is an enabler to many autonomous technologies," says Michael Thoeny, director of safety electronics at Delphi Electronics & Safety in Kokomo, Ind. Adding a short-range sensor on a car's back corners to detect vehicles in a driver's blind spot and a video camera pointed out the front windshield (plus visual-processing software) would essentially allow a car to keep itself in a lane, safely change lanes and largely avoid a collision. Ultimately, the same technologies could allow a row of vehicles to efficiently platoon down a highway lane in lockstep, although that vision may still take 10 years or more, Thoeny says.

Would drivers hand over so much control? "We're in a two-way learning process," says Andrew Whydell, product planning manager of active safety electronics at TRW Automotive in West Midlands, England. "Drivers are becoming more comfortable with electronics that take over, and manufacturers are learning how drivers react to and use these systems. Adding radars opens up options to many more automated features."

LONG-RANGE RADAR
or lidar (laser ranging) reflects off a vehicle ahead. The system senses if the time gap between the vehicles is shortening and emits an alarm if the gap closes dangerously fast. Short-range radar (just being rolled out) allows the car to stop and go automatically.



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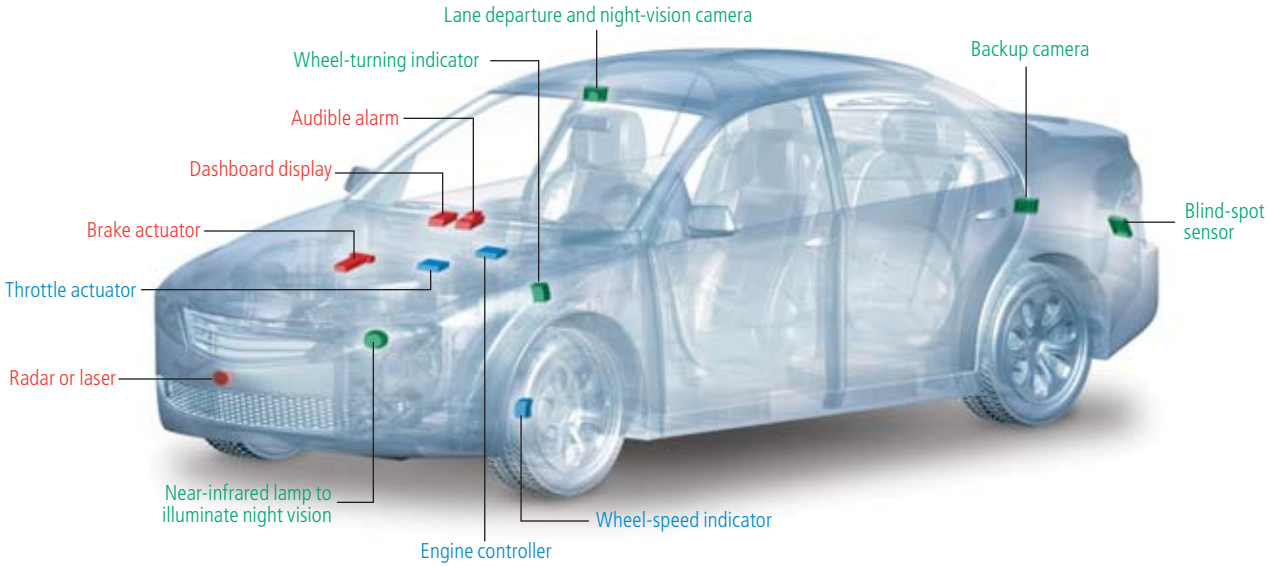
CRUISE CONTROL

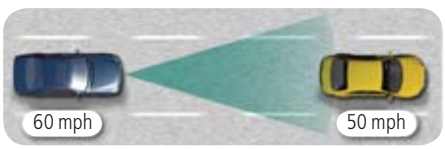
(*blue*) tracks wheel speed; the engine controller opens or closes the throttle to maintain the speed preset by the driver. Adaptive cruise control adds radar or lidar and other equipment (*red*) to track vehicles up ahead and closes the throttle or applies the brakes to slow the car.



FUTURE OPTIONS

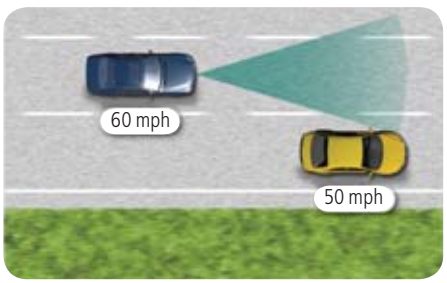
(*green*) that build on cruise technologies might include side- and rear-facing sensors to see vehicles in a driver's blind spot. A forward-looking camera would help radar keep a car between lane markers and could show a night-vision display on the windshield to assist drivers in spotting objects hidden by the dark.

Adaptive Cruise Control



Car slows when approaching a slower vehicle

Car follows at a steady time gap



Car accelerates when obstacle is gone

DID YOU KNOW ...

RADAR OR LIDAR: Radar-based adaptive cruise control, usually offered as an option on vehicles, can cost $1,300 to $2,400. Some manufacturers have therefore been using lidar (laser ranging), which can cut the cost by half or more. The laser beam, however, does not reflect well off dirty cars and can be scattered by fog, rain or snow. As a result, some automakers are switching from lidar to radar and betting that volume production and faster digital signal processors will lower costs.

SCAN AHEAD: Current cruise control radars have either a fixed antenna or a mechanically scanning antenna—one that rotates, improving angular measurements. Manufacturers would like eventually to replace both varieties with electronic scanning radar, which uses an array of fixed antennas and software algorithms to electronically sweep the beam, providing a wider field of view. The gear could also perform long- and short-range sensing, eliminating the need for two separate systems. A few early units are on the market but are very expensive.

Topic suggested by reader Bob Williamson.
SEND IDEAS *to workingknowledge@SciAm.com*

5W INFOGRAPHICS

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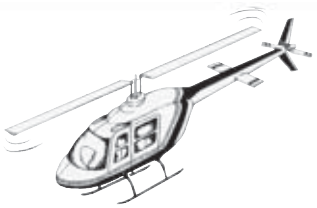
Books to Give ▪ Books to Get



BY MICHELLE PRESS

Of the many books sent to Scientific American *for possible review, some stood out as being especially appropriate for holiday gifts. They were unusually intriguing or unusually beautiful, most often both.*

The God Machine: From Boomerangs to Black Hawks, the Story of the Helicopter
by James R. Chiles. Bantam, 2007 ($25)
Profiles of the many helicoptrians who created this amazing contraption.

Storm Chaser: A Photographer's Journey
by Jim Reed. Abrams, 2007 ($42)
Chronicles remarkable floods, geomagnetic storms, the landfall of hurricanes.

Of a Feather: A Brief History of American Birding
by Scott Weidensaul. Harcourt, 2007 ($25)
Obsessive ornithologists from Audubon to today's "competitive" birders.

Cartographia: Mapping Civilizations
by Vincent Virga and the Library of Congress. Little, Brown, 2007 ($60)

More than 200 maps and their accompanying stories, from a 1500 B.C. cuneiform tablet to a 2001 map of the human genome. At the left, a globe from a World War II poster aimed at Middle Eastern allies of the U.S.

Very Special Relativity: An Illustrated Guide
by Sander Bais. Harvard University Press, 2007 ($20.95)
The fundamental concepts of Einstein's theory in a beautifully graphic book.

Arsenals of Folly: The Making of the Nuclear Arms Race
by Richard Rhodes. Knopf, 2007 ($28.95)
A gripping account of the standoff between the superpowers.

Discovering the Solar System
by David W. Hughes and Carole Stott. Barron's, 2007 ($29.99)
Includes a solar system mobile and an interactive wall chart.

Evolution
text by Jean-Baptiste de Panafieu. Photographs by Patrick Gries. Seven Stories Press, 2007 ($65)
A project from the Natural History Museum of Paris to demonstrate the reality of evolution through stunning photographs of animal skeletons and brief explanatory essays.

The Rough Guide to Genes and Cloning
by Jess Buxton and Jon Turney. Rough Guides, 2007 ($16.99)
The Rough Guide technique for unfamiliar lands applied to unfamiliar subjects.

The World without Us
by Alan Weisman. St. Martin's Press, 2007 ($24.95)
Easily the most fascinating environmental book of the year.

Talking Hands: What Sign Language Reveals about the Mind
by Margalit Fox. Simon & Schuster, 2007 ($27)
Discovering the basic ingredients of language in a remote village where everyone uses sign language.

Darwin's Origin of Species: A Biography
by Janet Browne. Atlantic Monthly Press, 2007 ($20.95)
Part of the Books That Changed the World series, by an acclaimed Darwin biographer.

How to Photograph an Atomic Bomb
by Peter Kuran. VCE, 2007 ($39.95)
A quirky combination of awesome (as in "shock and awe") photographs and technical details about how they were taken.

TOP PICK
America in Space: NASA's First Fifty Years

foreword by Neil Armstrong. 480 photographs. Published in collaboration with NASA to launch the celebration of its 50th anniversary. Abrams, 2007 ($50)

Beautifully reproduced on heavy matte paper in an exuberantly sized book (roughly 11 × 15 inches), these are not your usual space photos. Many have never been published, and all seem chosen for a sense of fun, novelty, and joy of life. Even the few old favorites convey new or amusing information—in a famous group portrait of the first seven astronauts, for example, we learn that Deke Slayton and John Glenn wear work boots spray-painted silver.

Among the many rare shots, the astronauts pose in 1963 while honing their survival skills in the Nevada desert, wearing outfits they fabricated under the strong influence of the popular film *Lawrence of Arabia.*

Left to right, front row: **Frank Borman, James Lovell, John Young, Pete Conrad, James McDivitt, Edward White;** ***back row:*** **Ray Zedehar (training officer), Thomas Stafford, Deke Slayton, Neil Armstrong, Elliot See.**

LIBRARY OF CONGRESS (*globe*); DTRA/DTRIAC (*camera setup*); LAURA MAESTRO (*helicopter*); NASA (*astronauts in desert*)

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Q How do **short-term** memories become **long-term** memories?

Alison Preston of the University of Texas at Austin's Center for Learning and Memory explains:

A short-term memory's conversion to a long-term memory requires changes within the brain that protect the memory from interference from competing stimuli or disruption from injury or disease. This time-dependent process, whereby experiences achieve a permanent record in our memory, is called consolidation.

The cellular and molecular portions of memory consolidation typically take place within the first minutes or hours of learning and result in changes to neurons (nerve cells) or sets of neurons. Systems-level consolidation, involving the reorganization of brain networks that handle the processing of individual memories, can then happen on a much slower time frame of days or even years.

The consolidation process that affects declarative memories—recollections of general facts and specific events—relies on the function of the hippocampus and other medial temporal lobe structures in the brain.

At the cellular level, memory is expressed as changes to the structure and function of neurons. For example, new synapses—the connections between neurons through which they exchange information—can form to allow for communication between new networks of neurons. Alternatively, existing synapses can be strengthened to allow for increased sensitivity in the communication between two neurons.

Consolidating such synaptic changes requires the synthesis of new RNA and proteins in the hippocampus, which transform temporary alterations in synaptic transmission into persistent modifications of synaptic architecture.

With time, the overarching brain systems also change. Initially, the hippocampus works in concert with sensory-processing regions distributed in the neocortex (the outermost layer of the brain) to form the new memories. Within the neocortex, representations of the elements that constitute an event in our life are distributed across multiple brain regions according to their content. For example, visual information is processed by the primary visual cortex in the occipital lobe at the rear of the brain, whereas auditory information is processed by the primary auditory cortex located in the temporal lobes on the sides of the brain.

When a memory is first formed, the hippocampus rapidly combines this distributed information into a single memory, thus acting as an index of representations in the sensory-processing regions. As time passes, cellular and molecular changes allow for the strengthening of direct connections among the neocortical regions, enabling access to the memory independent of the hippocampus. Thus, while damage to the hippocampus from injury or neurodegenerative disorder (Alzheimer's disease, for instance) hampers the ability to form new declarative memories, such a disruption may not impair memories for facts and events that have already been consolidated. ■

HANS NELEMAN *Getty Images*

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Q *Chocolate* ***Is Poisonous*** *to Dogs*

BY ALISON SNYDER

A small dog should be belly-up after eating a handful of holiday chocolates, at least according to pet owners' conventional wisdom. But watching Moose, a friend's five-pound Chihuahua, race around the living room after his sweet snack made me wonder: Is chocolate truly poisonous to dogs?

It is. The cacao bean, the central ingredient in chocolate, can sicken or, in some cases, kill members of the Canidae family.

The Chemical Culprit

Chocolate is processed from the bitter seeds of the cacao tree, which contain a family of compounds known as methylxanthines. This class of substances includes caffeine and the related chemical theobromine. Theobromine is abundant in chocolate, and caffeine occurs in smaller amounts. Both molecules bind to receptors on the surfaces of dogs' cells and block the canine-produced compounds that normally attach there.

Low doses of methylxanthines tend to produce euphoria in humans, but large amounts will cause muscle tremors or even bring on seizures in some dogs (so don't serve them coffee, either). Even relatively small amounts can lead to vomiting or diarrhea. Methylxanthines can also cause a dog's heart to race at up to twice its normal rate, and some dogs may run around as if "they drank a gallon of espresso," says Tim Hackett, a veterinarian at Colorado State University. Moose, it seems, was on a "theobromine high."

Doggy Differences

The danger of indulgence also depends on the type of chocolate scarfed down and on the animal's weight. Unsweetened baking chocolate contains more than six times as much theobromine as milk chocolate, although amounts vary among cacao beans as well as among the different brands of chocolate that are manufactured. In general, however, as little as an ounce of milk chocolate can sicken a beagle, and less than four ounces will sometimes kill dogs the size of Moose, according to the Animal Poison Control Center of the American Society for the Prevention of Cruelty to Animals.

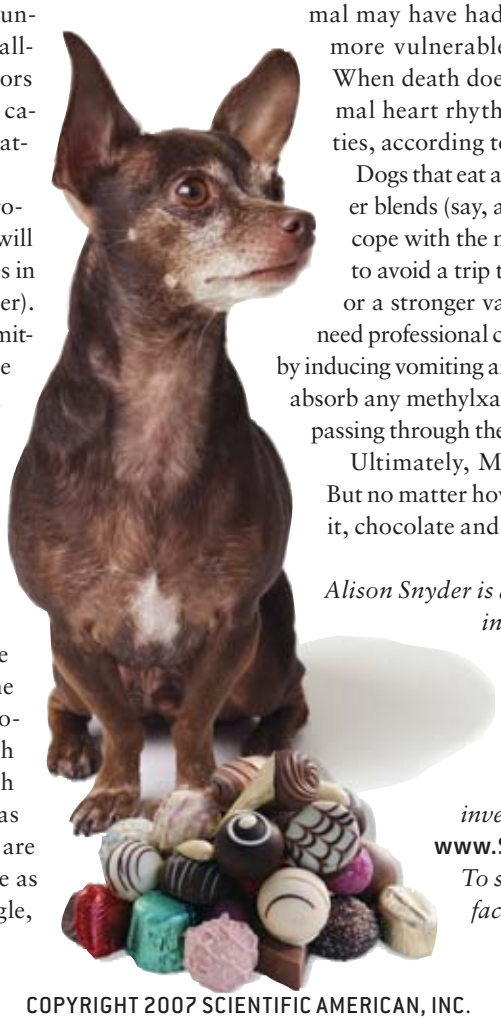
Many Survive

Still, people's fear that their dogs will die from eating some chocolate may be overblown, Hackett says. Around every confection-centered holiday—Valentine's Day, Easter and Christmas—at least three or four dogs are hospitalized overnight in the animal medical center at Colorado State, he notes. But in 16 years as an emergency and critical care veterinarian, Hackett has seen just one dog die from chocolate poisoning, and he suspects the animal may have had an underlying disease that made it more vulnerable to chocolate's heart-racing effect. When death does result, it usually stems from abnormal heart rhythms, high fever or breathing difficulties, according to the Merck Veterinary Manual.

Dogs that eat a small amount of milk chocolate or other blends (say, a handful of M&Ms) should be able to cope with the methylxanthines and may even be able to avoid a trip to the vet. But those that eat a lot more or a stronger variety (and thus are poisoned) usually need professional care. Such dogs can generally be treated by inducing vomiting and administering activated charcoal, to absorb any methylxanthines that remain in their gut or are passing through their digestive system.

Ultimately, Moose survived his ill-advised snack. But no matter how you bake it, wrap it, blend it or melt it, chocolate and dogs just don't mix. ■

Alison Snyder is a freelance science writer based in New York City.



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