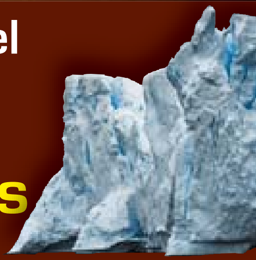
Cellular Invaders: Who Is Inside You? (page 72)

SCIENTIFIC AMERICAN

The Sea-Level Threat from **Sliding Ice Sheets**

page 60



February 2008 www.SciAm.com

SPECIAL REPORT

THE FUTURE OF PHYSICS

Hidden natural laws?
Unseen dimensions?
Two new particle colliders will search for answers at unimaginable energies

Scanning for Crime

RFID Chips Shrink to Fight Counterfeiters

Science Cities

Brazil's Bold Economic and Educational Plans

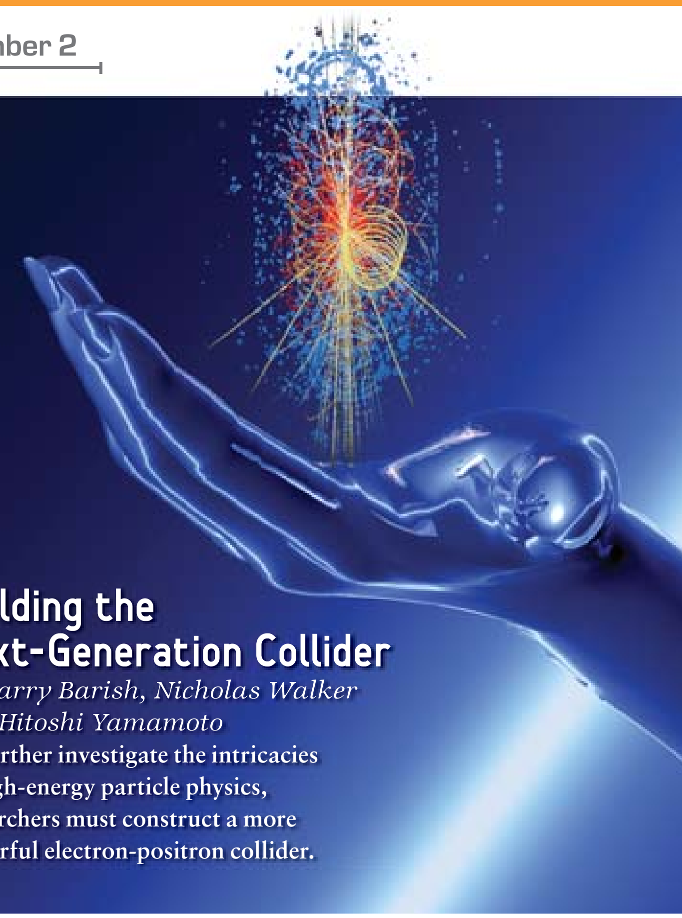
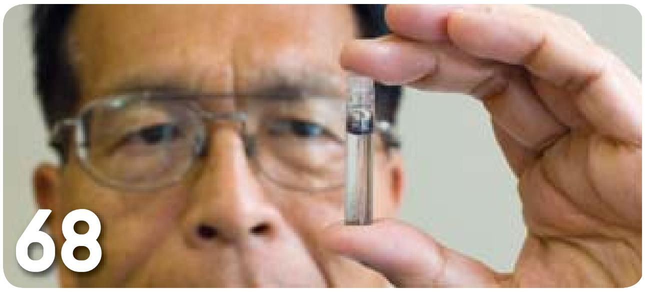


Image by CERN and Phil Saunders/Space Channel Ltd.



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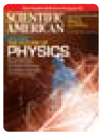
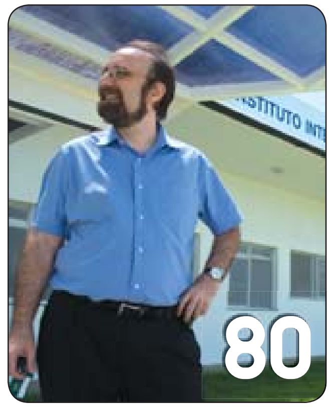


ON THE COVER
The Large Hadron Collider and a proposed International Linear Collider should propel humankind into a pristine realm of unknown particle physics. Image by Kenn Brown.



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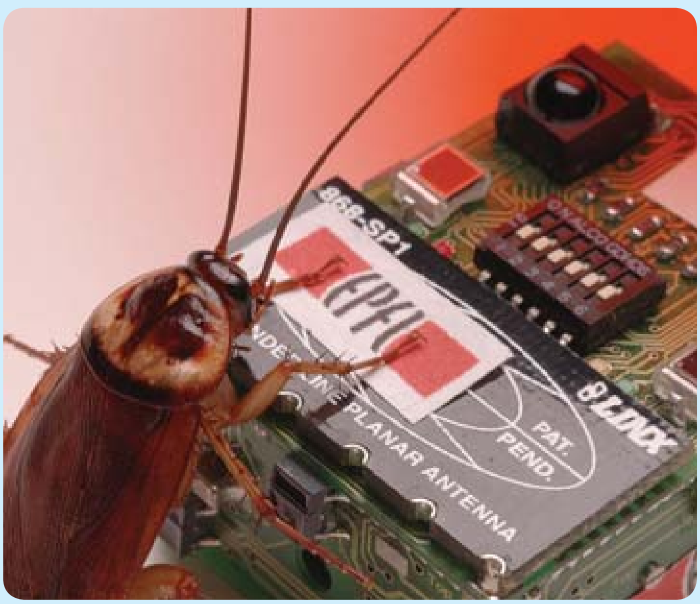
ROBOT ROACHES RALLY REAL ROACHES ▼

Tiny robotic roaches were able to influence the collective behavior of real ones, pointing the way to more sophisticated machine-animal interactions of the future. More at **www.SciAm.com/ontheweb**



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In Focus

Beyond the Worst-Case Climate Change Scenario

The IPCC has declared man-made climate change "unequivocal." The hard part: trying to stop it.

News

Partial Recall: Why Memory Fades with Age

The disruption of white matter conduits in the aging brain keeps its regions from communicating effectively.

Podcast

Dark Stars Bigger Than Solar Systems?

Early stars partially composed of dark matter may have been too bloated for fusion.

Video

What Is Dark Matter?

Our new video podcast kicks off with a quick take on the stuff that makes up most of the mass in the universe.

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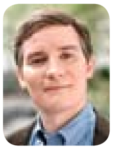
DEPARTMENTS

BRIAN MARANAN PINEDA

Presidential Science

Aspirants to the White House should publicly debate their views on science policy



Consider this partial list of issues that the next president of the U.S. will need to address: reducing greenhouse gas emissions; ensuring freshwater supplies; encouraging reliance on renewable energy sources; preparing for pandemics; developing stem cell technologies; improving science education; stimulating technological innovation.

How many of the current candidates for the presidency have stated clear positions on those subjects? What reasons would they give for their stances, and how well could they defend them? The answers could be broadly illuminating. The policies of the U.S. on such matters will be earthshakingly important in the years ahead, yet the candidates' intentions toward them have come in for little sustained attention thus far.

WILL THEY DEBATE over science?

One of the more notorious moments of the campaign season occurred last May during a debate among the Republican candidates, when three of them went on the record as not believing in the theory of evolution. Voters are undoubtedly better off knowing that to be true. It is at least as important, however, to know how all the candidates would set science priorities and direct technology to positive ends.

In December a grassroots bipartisan movement of concerned citizens operating as Science Debate 2008 issued a call for a debate that would focus exclusively on issues relating to the environment, health and medicine, and science and technology policy. Twelve Nobel laureates and other scientists are among the signatories to the petition, but so, too, are sitting congressional representatives, former presidential science advisers, business leaders and others (the list is still growing as this goes to press). Support has come swiftly from both Republicans and Democrats, as it should. I signed the petition on behalf of *Scientific American* and serve on the organization's steering committee. Readers can learn more about the effort online at www.sciencedebate2008.com.

A similar proposal for a "town hall" on science circulated during the 2004 presidential election, but it faltered. Here's hoping that this time the idea finds more traction with the campaigns. Our nation cannot afford to elect a president who is ill informed or dismissive about the role of science in making the world's future secure and bright.

Outside the U.S., at least one president positively glories in what science can do for his country. In her article "Building a Future on Science" (see page 80), staff editor Christine Soares describes the visionary plan that originated with neuroscientist Miguel A. L. Nicolelis of Duke University to promote economic development in a poor region of Brazil by establishing a new "science city" there. Centering on a well-financed research institution, such a cluster would cultivate the regional economy and raise the quality of local science education dramatically. Luiz Inácio Lula da Silva, president of Brazil, has become an enthusiastic supporter of this concept. In the Forum essay on page 33, Lula da Silva, Nicolelis and Fernando Haddad, Brazil's minister of education, announce a new initiative based on this concept that will extend science education and teacher training throughout the nation. We salute their enterprise and wish them well with this bold experiment. ■

JOHN RENNIE
editor in chief

FLYNN LARSEN (*Rennie*); ETHAN MILLER *Getty Images* (*debate*)

Among Our Contributors

ROBIN E. BELL investigates ice-sheet collapse and directs the ADVANCE program at the Earth Institute at Columbia University. She is also a leader in planning for the International Polar Year.

TIM HORNYAK covers new developments in science and technology from his home base in Tokyo. He is the author of the book *Loving the Machine: The Art and Science of Japanese Robots.*

J. LEE NELSON has been studying the medical implications of microchimerism for more than two decades. She is currently a professor of medicine at the University of Washington.

CHRIS QUIGG of Fermi National Accelerator Laboratory studies supercollider physics, with a particular emphasis on the symmetry breaking that should occur at terascale energies.

LETTERS

editors@SciAm.com

Drug Access ▪ Conservation Strategy ▪ Consciousness

OCTOBER 2007

> **"The difficulty in evaluating the health of a terminal cancer patient makes it very hard, in my opinion, to easily demonstrate the real benefit that a drug may show in a relatively healthier patient."**
> —*Joe Senesac* HOUSTON

Drug Dilemma

Beryl Lieff Benderly does an excellent job of summarizing the current state of the environment for access to experimental cancer drugs in "Experimental Drugs on Trial." A bigger issue that Benderly does not discuss, however, regards how the U.S. Food and Drug Administration and other regulatory agencies evaluate medicines for terminal disease states, particularly cancer.

Built into the evaluation process is the assumption that the truly sick individuals allowed to participate in clinical studies generate treatment data that are directly relevant to earlier-stage patients. Although this may be the case in many situations, it is used as a truism that is perhaps unprovable. The difficulty in evaluating the health of a terminal cancer patient makes it very hard, in my opinion, to demonstrate the real benefit that a drug may show in a relatively healthier patient.

We then encounter the ethical dilemma of whether to permit earlier-stage patients, who have more established treatment options, to use an experimental drug that has at least the potential to help them more than current (and painful) chemotherapy and radiation treatments. If we could find a way to allow earlier-stage patients access to experimental medicines that is ethical and that helps society as a whole, we might speed cancer drug development immensely.

Joe Senesac
Houston

Political Wilderness

In "Conservation for the People," Peter Kareiva and Michelle Marvier make the case that, because conservationists have not been able to build strong political support for protecting areas based on their biodiversity value, focus should instead be given to protecting areas that provide immediate benefits for people.

As in other political and social movements, failure to build support for a goal does not mean it should be abandoned. If the movements for abolition or civil rights had adopted Kareiva and Marvier's approach—making available to black Americans only such freedom and equality as whites saw as being in their near-term material interest—we would still be living with Jim Crow.

The authors drag out many straw men in making their argument, including the nonexistence of "pristine wilderness." Wilderness need not be pristine to sustain all native species in healthy populations, including top predators—animals essential to healthy ecosystems that some find "inconvenient." Wild places are essential because people's ability to manage nature successfully is limited. Experimentation with different approaches to conservation is fine but not at the expense of efforts to protect the lands and waters vital to the full range of biodiversity.

David Johns
School of Government
Portland State University

Michael E. Soulé
Professor emeritus
University of California, Santa Cruz

Pillow Perception?

In explaining their different theories of what brain activity matches up with specific conscious experiences in "How Does Consciousness Happen?" Christof Koch and Susan Greenfield each describe their views on why an alarm clock induces "consciousness" in a sleeping individual. Both fail to consider several factors in their assessments, and I feel that a better understanding of where "unconsciousness" ends and consciousness begins is needed.

For instance: Why is it that a person can sleep peacefully through many "common" sounds yet suddenly wake to the slightest "uncommon" noise? When I awaken to such sounds, I am more fully "conscious," or acutely aware of my surroundings, than if I am suddenly woken from sleep by the shrill call of the alarm clock. Furthermore, many people invariably awaken a few minutes before their alarm clock sounds.

All this suggests a rather high degree of consciousness and awareness of one's surroundings while sleeping.

Garry Wainscott
Perth, Australia

OF TWO MINDS: Christof Koch and Susan Greenfield disagree on what neuronal activity occurs during subjective experience.

Blastoff Bias?

"To the Moon and Beyond," by Charles Dingell, William A. Johns and Julie Kramer White, posits NASA's *Orion* space vehicle as a possible basis for a manned craft capable of traveling to Mars. The authors are all employees of NASA or Lockheed Martin (the lead contractor on the project), and this article represents a disturbing trend of presenting press releases or puff pieces as articles with journalistic integrity. A serious article on this project could have been written by a real science journalist, who would have weighed the claims of the NASA staff.

Gil Hennessey
New York City

The Hard Stuff

In "The Really Hard Science" [Skeptic], Michael Shermer laments the practice of labeling different fields of science as "hard" or "soft," with "hard" sciences respected as being more "difficult." This view is one I had not considered. I always saw physics and math as "hard," not because they are considered more difficult but because they can be somewhat constrained. The "soft" sciences are less possible to constrain—their "laws" are more subject to interpretation and harder to confirm experimentally. Computing a planetary orbit can be carried to many decimal places with accuracy. Determining the level of anger in a given population can only be computed with statistical uncertainty. The latter is probably more difficult and the former more reliable.

Richard Podraza
via e-mail

ERRATUM "Experimental Drugs on Trial," by Beryl Lieff Benderly, refers to a case being heard in March 2007 by the full nine-member U.S. Circuit Court of Appeals for the District of Columbia. There are 10 full-time judges in the court, who have all heard the case.

CLARIFICATION "Toxic Bulbs," by David Appell [News Scan], states that Australia will require citizens to replace incandescent lightbulbs with compact fluorescent lightbulbs (CFLs) by 2010. Australia plans to phase out the sale of incandescents, but working ones will not be removed. Other efficient light sources, such as light-emitting diodes, have not been ruled out.

Letters to the Editor

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

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BRIAN CRONIN

Gone Fission ▪ Wilbur on Flying ▪ Cold Steam

Compiled by Daniel C. Schlenoff

FEBRUARY 1958

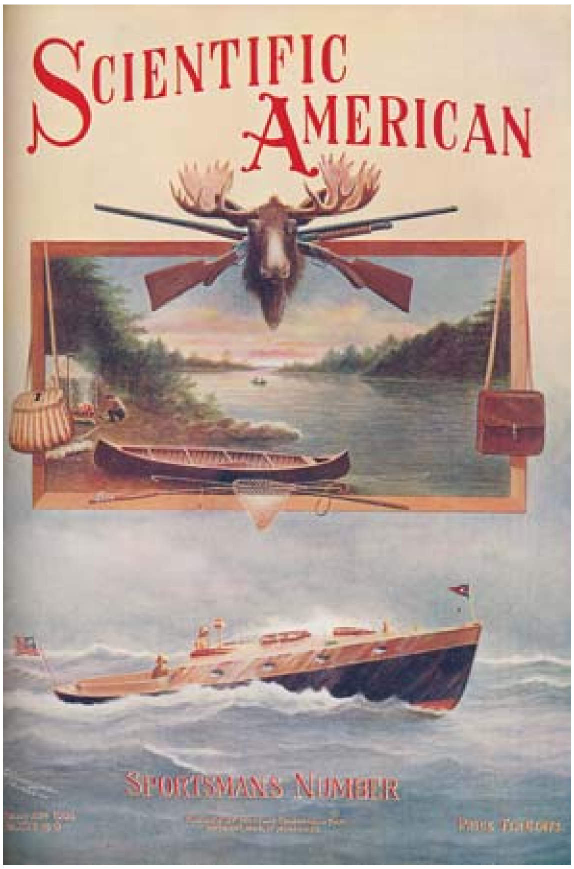
SPLITTING ATOMS—"In January, 1939, we published an account of 'experiments that are at variance with all previous experiences in nuclear physics.' In interpreting the experiments we expressed ourselves very cautiously, partly because the series of tests had not yet been quite finished—they took several weeks. But our caution was not due to any mistrust of our results. Indeed, we already had a strong check of our conclusion, for we had identified a decay product of one of our 'radium' isotopes as lanthanum, which meant that the parent had to be not radium but barium. Our overcautiousness stemmed primarily from the fact that, as chemists, we hesitated to announce a revolutionary discovery in physics. Nevertheless, we did speak of the 'bursting' of uranium, as we called the surprising process that had yielded barium, far down in the periodic table. —Otto Hahn"

[NOTE: Hahn won the Nobel Prize in Chemistry for 1944.]

CHAOS—"What U.S. universities need most is 'some peace and quiet and order,' according to J. C. Warner, president of the Carnegie Institute of Technology. In an article published last month, he said that Government emphasis on applied research has so disorganized university work that many scientists are 'living a life of intellectual chaos.' Their energies have been channeled away from teaching and creative research and often are dissipated in administrative work. Many scientists, he added, have become restless, 'to spend a semester or a year abroad, or in another institution … or on a glamorous missile or satellite project.' "

FEBRUARY 1908

SPORTSMAN'S NUMBER—"For this issue of Scientific American, a beautiful colored cover encloses a rare selection of appropriate articles interesting alike to the sportsman and to the general reader [*see illustration*]."



RECREATION, from traditional to mechanized, 1908

SCIENTIFIC AMERICAN, VOL. XCVIII, NO. 9; FEBRUARY 29, 1908

FLYING AS A SPORT—"Up to the present time men have taken up flying partly from scientific interest, partly from sport, and partly from business reasons, but a time is rapidly approaching when the art will have reached a state of development such that men can practice it without the necessity of maintaining a private laboratory or a manufacturing plant. Considered as a sport, flying possesses attractions which will appeal to many persons with a force beyond that exercised by any of the similar sports, such as boating, cycling, or automobiling. There is a sense of exhilaration in flying through the free air, an intensity of enjoyment. —Wilbur Wright"

The entire article from 1908 is available at **www.SciAm.com/ontheweb**

A HARD CLIMB—"When Mrs. Fanny Bullock Workman ascended Nun Kun peak of the Himalaya to a height of 23,260 feet above sea level, she made the world's record for mountain climbing by a woman. This ascent concluded a series of five seasons spent in the great mountain range by Dr. and Mrs. Workman, during which they traveled 1,300 miles along the 'roof of the world.' Mrs. Workman states emphatically that mountaineering conditions in Asia are far more arduous than those in Switzerland or the Rockies. Only by spending nights at higher altitudes than Alpinists have ever before rested, did she succeed in her record exploit."

FEBRUARY 1858

HOT AIR—"The Worcester (Mass.) *Spy* describes another of those brilliant inventions with which H. M. Paine is accustomed to dazzle the world, such as eclipsing the sun by his electric 'water-gas light.' The present new invention is nothing less than *a cold steam engine*. Paine generates steam without a boiler, from water which never boils, in a tank which never gets hot, and which is to take the place of the huge death-dealing steam boiler! A model of the engine has been exhibited to some admiring friends in Worcester, and the *Spy* states that 'the result is incredible (we doubt not) to any but those who actually witnessed it.' "

AIDS Accounting ▪ IPCC's Tough Talk ▪ Seasonal Spread ▪ Pollock Put-Down

Edited by Philip Yam

Downward Revision

The number of people living with HIV/AIDS globally has dramatically dropped—not because of an actual drop in the HIV burden but because of better counting methods in India. The Joint United Nations Program on HIV/AIDS (UNAIDS) and the World Health Organization announced last November that the disease's prevalence in India is 2.5 million—down by more than half from a previous estimate of 5.7 million. A commentary in the December 1, 2007, *Lancet* explains that previous official counts extrapolated data from large public hospitals. The revised figure derives from a national health survey of 102,000 adults and corroborates earlier findings from a smaller study. The lower estimate means that India will not need to devote as many resources to fight HIV and will not see the same infection rates as sub-Saharan Africa. The numbers support the current prevention strategy of targeting high-risk groups such as sex workers [see "The Prostitutes' Union"; Insights, SciAm, April 2006].

Flu in the Cold

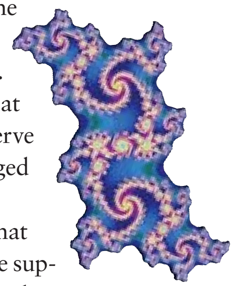
Influenza spreads most readily in winter, but crowding and closed windows have nothing to do with that seasonality. Rather cold air and low relative humidity seem to do the trick. Researchers found that infected guinea pigs kept at five degrees Celsius shed the bug for 40 hours longer than those kept near room temperature. The virus was most stable at relative humidities of 20 to 40 percent: dry air leads to smaller water droplets on which viruses are carried, enabling them to remain airborne for long periods. In the cold, cilia in the respiratory system work more slowly, enabling the virus to spread in the respiratory tract and to disperse in a sneeze or a cough. The study appears in the October 13, 2007, *PLoS Pathogens*.

Final Assessment

The Intergovernmental Panel on Climate Change (IPCC) released its fourth and final assessment on November 17, 2007. It synthesizes three preceding reports, which covered the science of climate change, ways the world could adapt and mitigation strategies [see "The Physical Science behind Climate Change"; SciAm, August 2007]. Notable in the synthesis is the more alarming language used—for instance, it cites "dangerous anthropogenic interference with the climate system" and notes that "delayed emissions reduction" increases the risk of more severe effects. Such urgency was lacking in past assessments because of objections by political delegates. Holding the report are IPCC chair Rajendra Pachauri (*left*) and United Nations secretary-general Ban Ki-moon (*right*).

Fractured Fractals

In authenticating artwork by Jackson Pollock, investigators have used a technique that is intended to extract certain geometric patterns thought to permeate the drip painter's signature splashes [see "Order in Pollock's Chaos"; SciAm, December 2002]. The technique is based on fractals, repeating patterns of varying scales, as seen in the so-called Julia set, shown at the right.



In 2006 physicists at Case Western Reserve University challenged the veracity of the method, arguing that the fractals that are supposedly unique to Pollock's work were also detected in amateur pieces. In an as yet unpublished paper, they continue their attack, showing that some genuine Pollocks failed the test, whereas amateur paintings intended to imitate Pollock's technique passed.

Richard P. Taylor, a University of Oregon physicist who originally designed the fractal analysis, claims the Case Western team has misapplied his technique, which, he says, should be used with other authentication methods, such as materials analysis. Taylor has examined six of a recently discovered cache of 32 suspected Pollock works, of which none so far has reached his mathematical criteria. *—Peter Sergo*

C SQUARED STUDIOS *Getty Images (sick boy)*; GREGORY SAMS *Photo Researchers, Inc. (fractal)*; FERNANDO BUSTAMANTE *AP Photo (IPCC meeting)*

STEM CELLS

Potent Alternative

Reverse-engineered human stem cells may leapfrog the embryonic kind BY JR MINKEL

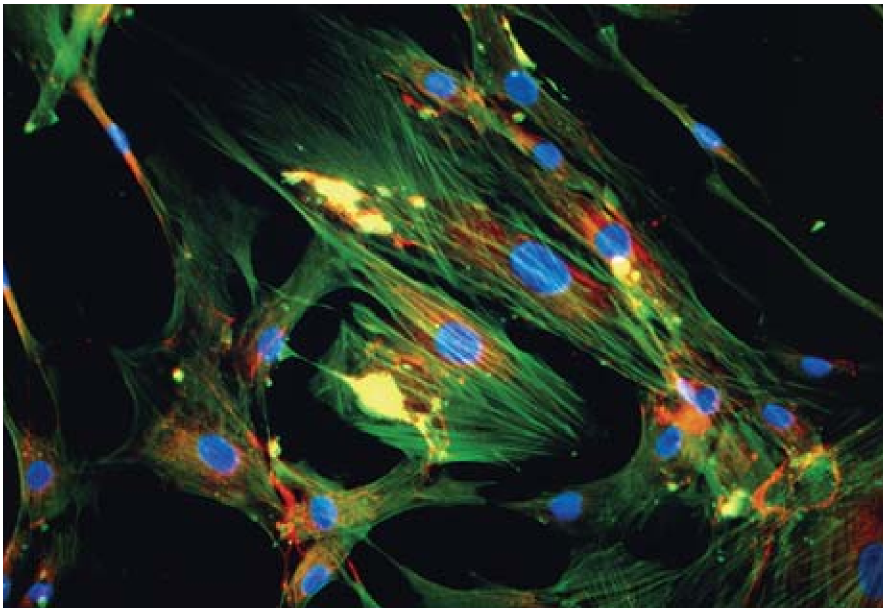
Ten years after introducing the world to Dolly the sheep, the first cloned animal, University of Edinburgh biologist Ian Wilmut announced last November that he was quitting the cloning game. He was not going out on a high note—neither Wilmut nor any of his colleagues had succeeded in cloning an adult human cell by implanting its nucleus into a properly prepared egg, yielding precious embryonic stem cells. Rather his announcement heralded the publication a few days later of a method for directly transforming human skin cells into a form that was essentially equivalent to the embryonic kind. Cloning, Wilmut told reporters, had become obsolete.

In principle, if the products of this transformation—called induced pluripotent stem (iPS) cells—are sufficiently versatile and defect-free, they could relatively quickly become the go-to source of stem cells for modeling disease more realistically, testing drugs and designing future therapies derived from cell lines matched to a patient's immune system. "All this now becomes much more tractable, and the prospect of not having to use human oocytes for this work is extremely attractive," says biologist Arnold Kriegstein, director of the Institute for Regeneration Medicine at the University of California, San Francisco.

The existence of Dolly demonstrated that reprogramming is possible; the question was how. An adult cell fused with an embryonic stem cell will adopt the embryonic state, according to a 2005 *Science* study, implying that some cocktail of gene products initiates the change. The very next year a group led by stem cell biologist Shinya Yamanaka of Kyoto University in Japan published a recipe for reprogramming mouse fibroblasts, cells found in connective tissue. The method called for inserting four powerful regulatory genes—*Oct4*, *Sox2*, *c-myc* and *Klf4*—into the cells' DNA, each delivered by its own retrovirus. Called transcription factors, these genes act like power strips, activating many other genes at once. The transformed cells passed a major test for embryonic "stemness," or pluripotency: when injected into a mouse embryo, they continued to develop into all three of the embryo's fundamental tissue layers.

Corroborating reports came earlier last year from the labs of Rudolf Jaenisch of the Massachusetts Institute of Technology's Whitehead Institute for Biomedical Research and Konrad Hochedlinger of the Harvard Stem Cell Institute. Then, in November, Yamanaka's group and an independent team at the University of Wisconsin–Madison, led by James Thomson, published reports in *Science* extending the technique to human fibroblasts. "I really thought this would be a 20-year problem, and it seems like it's going a lot faster than that," says Thomson, who in 1998 became the first to extract stem cells from a human embryo.

Notably, Thomson and his team created iPS cells without using *c-myc*, a gene that promotes cancer, although they reprogrammed neonatal and fetal cells only, not adult cells. Just a week later Yamanaka and



PROMISING OPTION: **Human skin fibroblasts can be changed by the addition of four genes into a form called induced pluripotent stem (iPS) cells, which act like stem cells. The image shows fibroblast nuclei (*blue*), cytoplasm (*red*) and actin fibers (*green*).**

NANCY KEDERSHA/IMMUNOGEN *Photo Researchers, Inc.*

his co-workers reported their own success transforming adult human and mouse fibroblasts without *c-myc* in *Nature Biotechnology*. Of 26 mice in Yamanaka's study derived from iPS cells, none died of cancer after 100 days, compared with six of 37 generated with *c-myc*.

In further refining the technique, investigators will have to replace the retroviruses used to deliver the genes. Retroviruses insert their DNA cargo into the genome at random, potentially interfering with key genes. Indeed it is conceivable—if unlikely—that the retroviruses could have activated *c-myc* in Yamanaka's latest iPS cells, says Jacob Hanna, a postdoctoral researcher in Jaenisch's group. One immediate goal of iPS research is to identify small molecules that could induce reprogramming in place of virus-delivered genes.

Whatever the source of pluripotent cells, applying them to cure disease is still largely uncharted territory. In a proof of principle for reprogramming, Hanna and others from the Whitehead lab reported in early December that they used iPS cells (with *c-myc* genetically excised) to partly restore to normal the blood of transgenic mice engineered to bear the human gene variant responsible for sickle-cell anemia.

Thomson and other developers of the new alchemy emphasize that embryonic stem cells remain invaluable research tools and will be crucial for confirming that iPS cells harbor no hidden limitations. Reprogrammed cells "might differ in clinically relevant ways from embryonic stem cells," Thomson notes. "People want to rush and say we don't need embryonic stem cells anymore, and over time that might be true, but right now that's premature."

EDUCATION

Arabian Brainpower

Can a $10-billion university restore science to the Islamic world? BY CHARLES Q. CHOI

On the shores of the Red Sea, near a small fishing village called Thuwal, King Abdullah of Saudi Arabia is launching a university with the ambition of making it a world leader in science and technology. Not only will the school—called King Abdullah University of Science and Technology (KAUST)—possess one of the 10 largest university endowments in the world, it will also allow women and men to study side by side. The greatest challenge that the potentially revolutionary school now faces is attracting faculty and students.

Science once flourished in the Islamic world, a legacy seen today in the West with the use of Arabic numerals and words such as "algebra." After the golden age of Islam ended with the Mongol invasion in the 13th century, this momentum vanished. "It's recognized in several [United Nations] reports that the Arab and Muslim world now lags behind in science," says Ahmad Al-Khowaiter, interim provost for KAUST. Such an assessment includes, for instance, the amount of money expended on research relative to the size of a country's economy and the total number of research papers published and patents registered.

To initiate world-class research in Saudi Arabia, King Abdullah is personally granting KAUST an endowment of $10 billion or more—at least as much as that of the Massachusetts Institute of Technology, which currently ranks among the top half a dozen university endowments in the U.S. The graduate-level university will be completely independent of Saudi Arabia's government, granting students and faculty academic freedom seen in universities worldwide—and a freedom unprecedented in the kingdom. "It will not experience the interference a typical government-run university may," Al-Khowaiter insists.

KAUST will enjoy the legal autonomy that is seen in enclaves elsewhere in Saudi Arabia for foreign oil workers—women will be allowed to drive, for instance, and the religious police will be barred from the premises. Although Al-Khowaiter expects some resistance to such freedoms from the rest of the kingdom, he believes that "if we can show that we are able to benefit society, I think that kind of resistance will be overcome. If we do not show benefits, then resistance will have the effect of curtailing research."

KAUST 2007

MODEL SCHOOL: **King Abdullah University of Science and Technology, which showed off its planned campus at its October 2007 groundbreaking, hopes to have 425 research faculty members and 2,000 graduate students.**

The nascent university's biggest challenge may be drawing top-rated talent to a geographically isolated

university with no track record. As enticement, KAUST will offer new labs with the best equipment and award grants to scientists. "Researchers won't spend 50 percent of their time chasing after funding," Al-Khowaiter says.

KAUST will also endeavor to overcome any isolation researchers might feel by keeping them linked with the rest of the world—allowing scientists to maintain appointments at other universities, for instance, and paying for travel to any meeting across the globe. In addition, KAUST will maintain a presence worldwide by collaborating with leading institutions, such as the Woods Hole Oceanographic Institution, and funding scientists at other universities with up to $1 billion in grants over a period of 10 years.

To attract students, the university will initially offer full scholarships, not only to all graduate students but also to overseas juniors and seniors to cover the remaining tuition at their current institutions in return for commitments to enroll at KAUST. The point is "to have a stream of students present when the university opens," Al-Khowaiter states. KAUST will give out these scholarships for at least its first 10 years.

Unusually, instead of organizing research around the single-discipline departments seen in most universities, KAUST will rely on interdisciplinary centers devoted to specific challenges, including energy research, water availability and sustainable development. "Such centers have been very successful worldwide in attracting scientists to work on big problems that require teams with many different disciplines," Al-Khowaiter says. In the end, KAUST is aiming for a student population made up of roughly 40 percent from Saudi Arabia and other Arab states of the Gulf region, 30 percent from countries stretching between Egypt and India, and 30 percent from the rest of the world.

"Given the large fraction of the population of young people in the Arab and Muslim world, there is a huge need for graduate and postgraduate study programs, especially of the quality that KAUST promises to deliver, and it is certainly time to offer such programs," says Ahmed Ghoniem, an M.I.T. mechanical engineer who is consulting for KAUST. "There is plenty of native brainpower that, if harnessed, can make a huge impact locally and globally."

Ultimately, King Abdullah wants Saudi Arabia to transform from a kingdom based on oil to a more knowledge-based society, Al-Khowaiter explains. If successful, he adds, other countries in the Arab and Muslim world might follow suit. As Frank Press, president emeritus of the National Academy of Sciences, puts it: "This could be a nation-changing enterprise."

Charles Q. Choi is a frequent contributor.

ADAPTATION

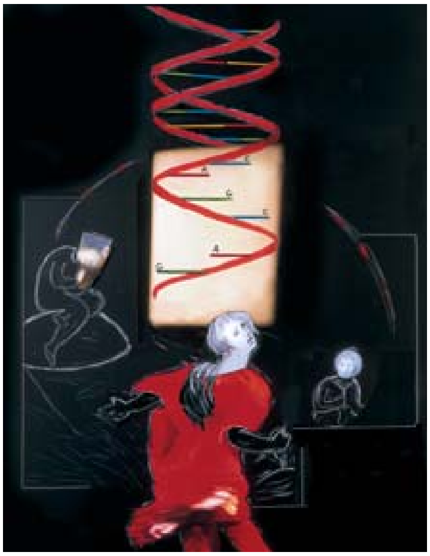
Disease for Darwinism

More kids, less cancer: Huntington's may confer survival benefits BY MELINDA WENNER

Over the past 35 years, scientists have made several curious discoveries about Huntington's disease. First, individuals with the neurological disorder are less likely than others to suffer from cancer; second, they tend to have more children than average—about 1.24 children for every one child born to unaffected siblings. Although no one yet knows what is behind these seemingly unconnected findings, a group at Tufts University has proposed that they are linked—and that one of the proteins implicated in Huntington's may, ironically, provide patients with subtle health benefits.

Huntington's destroys neurons in the neostriatum, a region of the brain associated with motor control and cognition. As a result, patients have difficulty controlling their movements and experience a range of cognitive and emotional problems. The disease is caused by a mutation that substantially lengthens a gene known as *huntingtin,* increasing the number of repeated sequences it contains. The length of the gene varies within the general population and becomes problematic only when it exceeds a certain extent. The gene's length also affects the severity of symptoms.

Although scientists do not know exactly why the mutation causes neurons to die, studies suggest that a protein called p53 plays a role. The protein has many diverse functions: it helps to regulate when cells divide and die and when new blood vessels form. In Huntington's, levels of p53 in the blood are higher than normal; p53 has also been shown to bind to the protein created from the mutant *huntingtin* gene. In addition, animals with the mutation seem to develop the disease only if their bodies can make p53. "The link between p53 and Huntington's disease is very important," says Akira Sawa, director of the Program in Molecular Psychiatry at Johns Hopkins University.



NATURALLY SELECTED? Mutation for Huntington's disease may be adaptive.

LESLIE JEAN-BART

Given the diversity of p53's functions, Philip Starks, a biologist at Tufts, and two of his students, Ben Eskenazi and Noah Wilson-Rich, recently speculated that increased p53 could be responsible for the disease's link to reduced cancer incidence and increased family size. "When Ben located published information on elevated p53 and relatively low cancer levels in Huntington's disease–positive individuals, it was a minor eureka moment for us," Starks explains. Because p53 regulates cell division, the protein helps to ward off cancer, so it is not ridiculous to think that higher levels might lower cancer risk, Starks says.

P53 also appears to play a part in immunity, leading Starks and his students to wonder whether Huntington's patients might also have heightened immune function during their childbearing years—a characteristic that could explain their increased family size. "We expect that the immune system should be positively related with reproductive success," explains Kenneth Fedorka, an evolutionary biologist at the University of Central Florida. Fedorka emphasizes, however, that the relation between immunity and reproductive success is complex; more research would be needed to tease out whether p53-triggered immune changes would actually lead patients to have more children. In any case, that Huntington's patients have more kids may explain why some studies suggest that the prevalence of the disease is slowly increasing. (Others maintain that doctors are simply making better diagnoses.)

Starks and his students believe that Huntington's is an example of antagonistic pleiotropy—a situation in which a gene has opposing effects on an organism. "The same pathological protein aggregates that debilitate Huntington's sufferers later in life may actually make them stronger and [more] reproductively successful in their prime," Eskenazi says. Such a mutation can survive, generation after generation, assuming that the deleterious effects do not appear until after childbearing years.

But that is a big assumption. Many people acquire Huntington's before or during their reproductive years, says Jane Paulsen, director of the Huntington's Disease Center at the University of Iowa. Although the average age of diagnosis is 39, it ranges from age two to 82, depending on mutation severity. "You're talking about such a small subsample of the population that really would have their presymptomatic years be commensurate with their reproductive years," Paulsen says.

And even if the disease does not fully develop until later in life, people with the gene often experience psychological changes such as depression and cognitive deficits many years before diagnosis, says David Rubinsztein, a molecular neurogeneticist at the University of Cambridge; these changes might influence their decision or ability to have children. "I'm not entirely convinced that patients who have Huntington's disease are necessarily more

fecund than those who don't," he says.

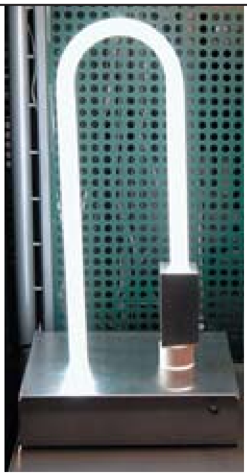
Starks points out that his model, published in the November 13, 2007, *Medical Hypotheses,* is indeed speculative. He hopes, however, his ideas linking increased p53 to reduced cancer risk and increased family size will spark further studies. Paulsen agrees that even if the model is wrong, it is certain to raise interest and is a good thing. "What does provocation do to science?" Paulsen asks. Ideally, "it makes it better. That's what hypotheses are for."

Melinda Wenner is a freelance writer based in New York City.

COMMUNICATIONS

Aerial Stealth

Plasma antennas disappear when shut off BY STEVEN ASHLEY



ANTENNA VANISHES from radar when the electricity fed to a plasma-filled tube is cut off.

HALEAKALA RESEARCH AND DEVELOPMENT, INC., COURTESY OF THEODORE ANDERSON

Radar uses radio waves to enable aircraft, ships and ground stations to see far into their surroundings even at night and in bad weather. The metal antennas behind those waves also strongly reflect radar, making them highly visible to others—a deadly disadvantage during wartime. A new class of nonmetallic radio antennas can become invisible to radar—by ceasing to reflect radio waves—when deactivated. This innovation, called plasma antenna technology, is based on energizing gases in sealed tubes to form clouds of freely moving electrons and charged ions.

Although the notion of the plasma antenna has been knocked around in labs for decades, Ted Anderson, president of Haleakala Research and Development—a small firm in Brookfield, Mass.—and physicist Igor Alexeff of the University of Tennessee–Knoxville have recently revived interest in the concept. Their research reopens the possibility of compact and jamming-resistant antennas that use modest amounts of power, generate little noise, do not interfere with other antennas and can be easily tuned to many frequencies.

When a radio-frequency electric pulse is applied to one end of such a tube (Anderson and Alexeff use fluorescent lamps), the energy from the pulse ionizes the gas inside to produce a plasma. "The high electron density within this plasma makes it an excellent conductor of electricity, just like metal," Anderson says. When in an energized state, the enclosed plasma can readily radiate, absorb or reflect electromagnetic waves. Altering the plasma density by adjusting the applied power changes the radio frequencies it broadcasts and picks up. In addition, antennas tuned to the right plasma densities can be sensitive to lower radio frequencies while remaining unresponsive to the higher frequencies used by most radars. But unlike metal, once the voltage is switched off, the plasma rapidly returns to a neutral gas, and the antenna, in effect, disappears.

This vanishing act could have several applications, Alexeff reports. Defense contractor Lockheed Martin will soon flight-test a plasma antenna (encased in a tough, nonconducting polymer) that is designed to be immune from detection by radar even as it transmits and receives low-frequency radio waves. The U.S. Air Force, meanwhile, hopes that the technology will be able to shield satellite electronics from powerful jamming signals that might be beamed from enemy missiles. And the U.S. Army is supporting research on steerable plasma antenna arrays in which a radar transmitter-receiver is ringed by plasma antenna reflectors. "When one of the antennas is deactivated, microwave signals radiating from the center pass through the open window in a highly directional beam," Alexeff says. Conversely, the same apparatus can act as a directional receiver to precisely locate radio emitters.

Not all researchers familiar with the technology are so sanguine about its prospects, however. More than a decade ago the U.S. Navy explored plasma antenna technology, recalls Wally Manheimer, a plasma physicist at the Naval Research Laboratory. It hoped that plasmas could form the basis of a compact and stealthy upgrade to the metallic phased-array radars used today on the U.S. Navy's Aegis cruisers and other vessels. Microwave beams from these arrays of antenna elements can be steered electronically toward targets. Naval researchers, Manheimer recounts, attempted to use plasma antenna technology aimed by magnetic fields to create a more precise "agile mirror" array. To function well, the resulting beams needed to be steered in two dimensions; unfortunately, the scientists could move them in only one orientation, so the U.S. Navy canceled the program.

Signal Clouds

Having taken heavy casualties, your reconnaissance team is cut off deep within enemy territory. You need extraction fast, but the surrounding mountains are blocking your communications. What do you do? Plasma antenna researchers may have a solution. Several have patented a concept by which antennas relying on plasma gas could transmit and receive signals when more conventional communications links fail. Essentially, explosive charges would propel a jet of plasma high into the air, and the resulting cloud of ionized gas would then strongly propagate electromagnetic signals from a special radio set.

MEDICINE

From Race to DNA

Thinking about patients as ongoing products of evolution BY SALLY LEHRMAN

Even as biomedical researchers generate and dig through mountains of gene sequence data, physicians proceed in the clinic as they always have. They design preventive care, plan treatments and select drugs by assessing patient type—frequently with race and ethnicity central. Molecular biologists often look to these categories, too, as a means to sort out the ways in which gene variants influence patient response to drugs and disease. And if they get federal funding, investigators must divide the groups they study by race.

Now evolutionary biologists are leading a shift in perspective. Lumping people by the social categories of race, they argue, can hide patterns of biological variation and lead to misinterpretation. And although ancestral population groups may be important, more comprehensive evolutionary thinking would help doctors and researchers predict patient response, design studies and interpret the associations seen between genes and disease susceptibility. Race isn't meaningless, says Lynn Jorde, an evolutionary geneticist at the University of Utah, but "those categories are only marginally useful."

Evolutionary medicine has long served to explain how some genes can be harmful in one context but beneficial in another. In one iconic example, having two copies of a mutated hemoglobin gene causes sickle-cell anemia, but having one copy protects against malaria. Now the field aims to offer insight that might lead to a true "personalized" medicine—one that takes into account not just population history but also the dynamic of human variation, environment and selection pressures that acts on each individual today.

Genetics researchers have begun to move in this direction by replacing "race" with "ancestry." As early humans spread out from Africa, some variation arose in human DNA that remains today. By sampling enough groups from enough locations, investigators hope to identify adaptive changes that might differ by ancestral location and be important to health.

Even that approach, however, might

oversimplify human variation and whatever functional meaning it has. Many population studies divide the world into three primary ancestral groups—usually sub-Saharan African, East Asian and European—roughly representing migrations out of Africa. But these categories not only can be hard to distinguish from "race," they also ignore the overlap between groups and the continuous nature of the way people and genes spread today. "What we see is this wonderful, intertwined history," Jorde remarks.

Evolutionary theory would predict that most genetic variants important to health are common, ancient and thus shared, whereas some rare variants may be quite population-specific. Even so, more recent "microevolution" caused by mutations, selection and genetic drift in each generation continues to shape our genes beyond the template set by ancient migrations. One example comes from Steven J. Mack of the Children's Hospital & Research Center Oakland in California, who explores HLA, a cell-surface molecule that plays a role in self-nonself recognition and several kinds of disease. Mack and his collaborators studied 20 populations and found that the greatest diversity in the frequency of gene variants lay outside Africa. Surprisingly, populations in Africa, Europe and Southwest Asia looked similar to one another in terms of frequency of common polymorphisms; Oceania and the indigenous Americas had much more variation. Fresh diversification arose, Mack theorizes, as these smaller, isolated populations confronted new pathogens.

Diddahally Govindaraju, director of the Framingham Heart Study Genetics Laboratory in Boston, says a simple equation that attempts to trace high disease risk to susceptibility genes in a population grouped by ancestry will often fail. Without evolution as a framework, he contends, "the questions are off, the interpretations are off." Gene action must be understood in the context of adaptive and sometimes haphazard trade-offs as well as developmental stages, the history of human colonization and the pace of environmental change.

Population movement indeed seems to have accelerated changes in human DNA. A study in the *Proceedings of the National Academy of Sciences USA* found that genes have changed more in the past few thousand years than in the past few million because of altered living conditions. Govindaraju emphasizes that this change is ongoing and does not limit itself to historical populations. A gene that powerfully influences someone's asthma in India, say, might be irrelevant when that person is living in the U.S. "A population is only a population," he explains, "in that environment."

Govindaraju has helped convene a working group funded by the National Evolutionary Synthesis Center in Durham, N.C., that brings together specialists from evolutionary biology, human genetics, anthropology, public health and medicine. The team will start by analyzing data collected in the Framingham Heart Study to document microevolutionary changes over three generations.

Typing people by race or even ancestry, Govindaraju adds, locks clinicians into a static understanding of genes and health. Instead he hopes they will begin to see an individual and the network of genes within the body as an integrated product of family, generation, location and history—and as an organism that is still evolving.

Sally Lehrman is based in the San Francisco Bay Area.

PATIENT CHANGES: **To get beyond race, a new movement wants physicians to see patients as products of evolution.**

PAUL SAKUMA *AP Photo*

DEFENSE

Proactive Prototypes

For new tech systems, a return to competitive prototyping BY DANIEL G. DUPONT

Last March a group of Alabama lawmakers met with the Pentagon's top acquisition official to discuss a new program, the Joint Air-to-Ground Missile (JAGM). The lawmakers—looking out for the city of Huntsville, a legendary missile development hub—wanted to know what came next. The official told them the usual process was at work: the military would run a competition for JAGM and pick one contractor to develop it.

A few months later, though, those same lawmakers demanded to know why the usual process would no longer be followed—they had just learned a new plan called for the Pentagon to pick at least two teams to compete against each other, and they weren't happy about it.

What had happened was that a new sheriff had come to town—or rather a new top acquisition official, John Young. Last September, Young issued a policy that went beyond competitive bidding and resurrected an old idea: competitive proto-

COMPETITIVE PROTOTYPING for the Joint Strike Fighter led to Boeing's X-32 (*left*) and Lockheed's X-35, but some say the competition did not go far enough.

typing. Every Pentagon development program, he decreed, had to involve at least two prototypes early on—to be developed by competing industry teams—before the military could decide whether to move forward into what it calls the system design and development phase, the lengthiest and costliest part of the process.

The military has used competitive prototyping on occasion, most notably in major aircraft efforts such as the F-35 Joint Strike Fighter, the largest program in Pentagon history. But Young's memo decried a pattern among "many troubled programs" that were pushed forward before they were ready, wasting time and billions of dollars. The problem, in part, was that defense officials often made decisions "based largely on paper proposals that provided inadequate knowledge of technical risk and a weak foundation for estimating development and procurement costs," he wrote.

The Government Accountability Office (GAO) agrees. In a March 2005 review of more than 50 major weapons systems, GAO auditors found that only 15 percent "began development having demonstrated all of their technologies mature." And development costs, the GAO found, increased an average of 41 percent in these cases, compared with a 1 percent increase in systems that began with mature technologies.

Prototypes pitted against one another, Young contends, will give developers a better idea of a technology's maturity long before large amounts of money have been spent—and well before a program becomes entrenched in the Pentagon and congressional budget process, when many troubled efforts persist despite huge problems because of so many vested interests. He also believes that an emphasis on "quality prototyping" will help reduce the time needed to field key technologies—hence, the decision to change the acquisition strategy for the JAGM program before it proceeded too far, too fast.

Philip Coyle, the Pentagon's top weapons tester during the Clinton administration, lauds Young's push. During his time in the Pentagon, Coyle encountered many programs that eschewed competition early "in the interest of saving time" and money, "but it always turns out that's not the case," he says. One example: the tilt-rotor V-22 Osprey, now flying in Iraq after 20 years of problematic development. Aggressive, competitive prototyping might have shaved years off of the program's development timetable, Coyle states.

Jacques Gansler, the undersecretary of defense for acquisition, technology and logistics under President Bill Clinton, concurs with Coyle. "Too often we have jumped into programs without proving the technology," he says. With prototypes employed early on, Gansler argues, the Pentagon has benefited. One example: the F-16 fighter competition in the 1970s.

More recently, the Joint Strike Fighter program began with a competition involving prototypes built by Boeing and Lockheed Martin. Defense officials flew both aircraft extensively before choosing Lockheed's variant, now called the F-35. Coyle, while praising that early prototyping effort, says that the Pentagon stopped the competition too soon. Today, he notes, F-35 "costs are rising, and schedules are slipping"—total program costs have increased to a projected total of $100 billion, according to the Congressional Research Service. The lesson from the Joint Strike Fighter, he believes, is that the Pentagon must carefully define what prototypes are.

Young's push to make prototyping the norm will not be easy. It will add costs up front, when money is scarcest and support is weakest. And it may run up against a belief that certain programs must be pushed at great speeds to fill capability gaps—exactly the reasons behind the Alabama lawmakers' interest in moving forward quickly with JAGM. "John Young recognizes that there is a major cultural bias against competition that is ingrained in the [Department of Defense], and he's trying to change that culture," Coyle remarks.

Defense spending will likely plummet during the next few years, Gansler says, so acquisition reform will become more important than ever. Instilling a competitive environment should be given high-level support even if the result is that some initiatives have to go back to the drawing board. The Pentagon, he says, "can't afford not to."

Daniel G. Dupont edits InsideDefense.com, an online news service.

Attracting the Next Generation

The Pentagon's John Young believes that competitive prototyping will not only yield better weapons systems but will also help alleviate a problem facing both the military and the defense and aerospace industry: a paucity of young scientists and engineers. According to a study by Aerospace Corporation, the number of master's degrees in science and engineering awarded to U.S. residents has been falling by an average of 5 percent a year since 1995. Young's memo on prototyping states that more competition during the early research stage could entice "young scientists and engineers to apply their technical talents to the needs of our nation's warfighters" and could "inspire the imagination and creativity of a new generation of young students."

EVELYN KRISTO *Antelope Valley Press/AP Photo*

VISION

Turning a Blind Eye?

Proponents fire back after a report questions glaucoma screening BY ALISON SNYDER

In revamping Medicare, one of the first preventive practices President George W. Bush put under the national health care policy was glaucoma testing, beginning in 2002. After all, screening people at high risk of developing the chronic eye disease had been common practice for decades. Then, in 2005, a government-sponsored panel of experts found that it could not make any definitive recommendation about glaucoma screening. The surprising conclusion sparked a debate over the risks and benefits of screening for the disorder. Now new evidence, some researchers and policymakers say, tips the balance in favor of the benefits.

Glaucoma affects about three million people in the U.S. and is a leading cause of blindness. It occurs when fluid pressure inside the eyes rises, irreversibly damaging the optic nerve that carries visual information from the retina to the brain. Blind spots begin to form on the periphery of people's vision and can progress to tunnel vision that, left untreated, can then narrow to blindness.

HOLD STILL: The benefits of glaucoma screening were challenged by a 2005 government report.

As many as half of those with glaucoma in the U.S. do not know that they have the disease, according to the National Eye Institute. "There are no symptoms or signs. The disease is essentially picked up through screening," explains Rohit Varma, an ophthalmology professor at the University of Southern California. Such screening typically involves checking a patient's peripheral vision, examining the retina and optic nerve for damage and measuring the fluid pressure in the patient's eye. Testing is important because a loss of vision cannot be reversed. Prescription eyedrops or surgery, or both, however, can halt its progression.

The National Eye Institute and other government agencies, professional societies and consumer groups recommend regular glaucoma screening for people at high risk, such as individuals with a family history of the disease, African-Americans older than 40, and everyone older than 60, especially Latinos. But in 2005 the U.S. Preventive Services Task Force (USPSTF), a panel of primary and preventive care experts sponsored by the U.S. Department of Health and Human Services, evaluated the scientific literature regarding testing and "found insufficient evidence to recommend for or against screening adults for glaucoma."

In reviewing 13 studies, the task force saw evidence that screening can detect increased fluid pressure and early glaucoma in adults and that timely treatment for fluid pressure reduces the number of people who lose their vision from the disease. But it did not find enough evidence to determine whether screening and early detection lead to improved quality of life for glaucoma patients. Moreover, the task force cited eye irritation from screening and an increased risk for developing cataracts after glaucoma treatment as associated risks. So the panel did not recommend for or against screening. The apparently neutral stance effectively states that "the benefits don't outweigh the risks," comments Dennis McBride, academic president of the Potomac Institute for Policy Studies, a nonprofit public policy research group.

Concerned that the report would affect insurance coverage for glaucoma screening, the Potomac Institute and the Glaucoma Foundation held a conference last October to discuss national guidelines for glaucoma testing and treatment. Researchers also presented evidence that directly addressed the USPSTF question about quality of life. One such investigation, which is part of the larger Los Angeles Latino Eye Study, measured the extent of patients' tunnel vision and asked them to describe how their condition affected their routines. Those with tunnel vision had the greatest difficulties with driving and activities that relied on distance and peripheral vision, and they scored lowest on surveys of mental health and dependency, researchers reported. "We've shown quite well that even with very early vision field loss, people's daily lives are affected," says Varma, who leads the study.

When contacted for this story, the USPSTF declined to comment, citing confidentiality in its deliberations. But McBride hopes in light of the new data, the task force will reevaluate the evidence for glaucoma screening and treatment ahead of its scheduled review in 2010. In summing up our value of sight, he remarks: "Older people are more afraid to lose their vision than to lose their life."

Alison Snyder, a freelance writer, is also an associate producer for the World Science Festival, which is organizing its first annual weeklong exploration of science later this year in New York City.

HUY NGUYEN *Dallas Morning News/Corbis*

BIOLOGY

Fungus Cowboys

The oldest known carnivorous fungus, unearthed in 100-million-year-old amber, apparently lassoed its worm prey with sticky loops. Modern carnivorous fungi are armed with constricting rings and other projections they use to trap prey, but scientists had been unsure of when these snares evolved. Amber from what once was a coastal tropical forest in southwestern France revealed fossilized fungi with their nematode quarry. The carnivores possessed branched filaments adorned with small rings plastered with tiny particles, suggesting that the rings were sticky. Several of the worms were located near rings, and their width roughly matches that of the loops, hinting that the nematodes served as prey. Once ensnared, the worms were devoured with infestation filaments, speculate scientists from Humboldt University of Berlin and elsewhere. The scientists suggest that carnivory in fungi is ancient in origin. Digest more in the December 14, 2007, *Science*. —*Charles Q. Choi*

TRAPPING RING of an ancient carnivorous fungus is preserved in amber.

FISHERIES

Reduced Catch for Net Gain

The profit motive that has driven the world's fisheries to near collapse could also save them. In a review of four fisheries, economists at the Australian National University in Canberra and the University of Washington conclude that reducing fishing yields in the short term boosts fishing profits in the long run. The reason: as fish become more plentiful, it costs less to catch them. There is a catch: the people who reduce their catch to rebuild stocks need to be the same ones that benefit from the reduced costs of fishing, which implies some form of exclusive access. Moreover, people who are not fishing now because it is unprofitable cannot be allowed to join in later. "Individual transferable quotas" would give fisherfolk shares in a total allowable catch, the economists suggest. Fishery managers in Alaska and New Zealand have tried such a system with positive results. Reel in the analysis from the December 7, 2007, *Science*. —*David Biello*

PERCEPTION

Brain of the Beholder

People suffering from body dysmorphic disorder perceive themselves as ugly, fixating on a slight abnormality or an imagined flaw. The condition can lead to repeated plastic surgery and increased risk of suicide. This distorted self-image may not result solely from society's focus on appearance but from a visual brain glitch that literally makes people see the world differently. Scientists at the University of California, Los Angeles, outfitted 12 patients with goggles that showed digital images of faces. These pictures were either untouched photographs, line drawings of faces, or images that had freckles, wrinkles and other facial details blurred out. Functional magnetic resonance imaging revealed that people with the disorder used their brain's left side—the part attuned to complex details—more often than normal. These findings could one day help retrain brains to perceive faces more accurately. Face up to it in the December 2007 *Archives of General Psychiatry*. —*Charles Q. Choi*

Data Points

Ounces of Prevention

Vaccines may not be the moneymakers that drug firms like, but they have transformed U.S. health. A study looking at the prevaccine and postvaccine eras finds that of 13 childhood vaccinations, nine showed at least a 90 percent decline in death and in hospitalization rates. Today's nonimmunized child typically comes from a well-to-do family granted religious or philosophical exemptions, rather than from a poor family lacking insurance, as was the case in the past.

Vaccines approved before 1980 prevent diphtheria, measles, mumps, pertussis, poliomyelitis, rubella, smallpox and tetanus; vaccines approved since then target hepatitis A, acute hepatitis B, *Hemophilus influenzae* b (Hib), *Streptococcus pneumoniae* and varicella (chicken pox).

Annual average number of disease cases in prevaccine era for vaccinations recommended before 1980 (covering eight diseases): 1,027,958

Annual average number of cases in postvaccine era: 22,324

Annual average number of cases in prevaccine era for vaccinations first recommended after 1980 (covering five diseases): 4,351,752

Annual average number of cases in postvaccine era: 682,835

Estimated annual deaths from all 13 diseases in:

Prevaccine era: 18,412

Postvaccine era: 4,970

Postvaccine era, excluding strep: 120

SOURCE: Journal of the American Medical Association, *November 14, 2007*

SCIENCE/AAAS (*top*); RUBBERBALL/GETTY IMAGES (*bottom*); ILLUSTRATION BY MATT COLLINS

In Brief

COOLING SEAS

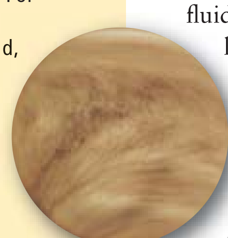
Humans could boost the seas' ability to absorb carbon dioxide from the air. Harvard University geoscientist Kurt House and his colleagues propose coastal treatment plants that bring in seawater and run electric current through it to extract acid. This process would raise the seawater's alkalinity, enhancing its natural ability to absorb atmospheric CO_2. Silicates in volcanic rocks could neutralize the acid. About 100 such plants could cut global carbon dioxide emissions by 15 percent, the researchers say in the December 15, 2007, *Environmental Science & Technology,* but they caution that the alkaline seawater could kill marine life near these plants. *—Charles Q. Choi*

E-WASTE OUTPACES THE LAW

The Environmental Protection Agency says that recycling of old electronics gear is needed to keep a lid on growing piles of "e-waste." But the EPA lacks the power to mandate such action. In 2005 the U.S. generated 2.6 million tons of e-waste (1.4 percent of the country's total waste stream); only 12.6 percent of it was recycled. The problem will grow as consumers replace computers, televisions and cell phones—all of which contain toxic substances. In contrast to U.S. inaction, the European Commission has limited the flow of e-waste since 2003, and some legislation there demands greener manufacturing. In the absence of federal law, nine U.S. states have instituted their own take-back rules. *—Larry Greenemeier*

TWISTED SISTER

The European Space Agency's Venus Express orbiter has revealed just how different Earth's twin really is. For instance, Venus's atmosphere, unprotected by a magnetic field, encounters fierce solar winds that rip apart molecules and send them out into space. Investigators discovered that twice as much hydrogen is leaving Venus as oxygen, suggesting that water is being driven off. Based on the data, perhaps an ocean's worth of H_2O has departed Venus since the planet formed. The orbiter also confirmed that Venus's atmosphere produces its own lightning. *—Nikhil Swaminathan*



ASTROPHYSICS

Brightest Supernova May Reignite

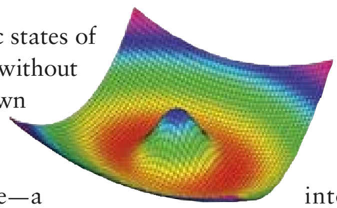
An ultrapowerful supernova discovered in 2006 may blow its top again. Burning 100 times brighter than a typical supernova, SN 2006gy maintained full strength for an amazing three months. To explain the massive outburst, researchers invoked a mechanism called pair instability, in which high-energy gamma rays inside the star convert into pairs of electrons and positrons, draining stellar energy that would normally help maintain its internal pressure. That sapping leads to a premature collapse, liberating vast amounts of energy and light. Astrophysicists now report that SN 2006gy's brightness changes fit a model of pulsating pair instability. In this scenario, the initial implosion of a 110-solar-mass star would shed several suns' worth of mass before igniting the star's carbon and oxygen fuel, temporarily halting the collapse. Roughly seven years later pair instability would cause a second breakdown that would emit a smaller but faster pulse of material. The study appears in the November 15, 2007, *Nature.* *—JR Minkel*

BIG BLAST: Artist's rendition of what supernova SN 2006gy might have looked like up close.

PHYSICS

Going with the Persistent Flow

Near absolute zero, exotic states of matter can bizarrely flow without friction. Physicists have known that, in principle, everlasting flows are possible in a Bose-Einstein condensate—a pool of ultracold particles that essentially behave as one superparticle—but have failed to see them. Now National Institute of Standards and Technology researchers have created a doughnut-shaped condensate with persistent circular superfluid flows lasting up to 10 seconds. Unlike past condensates, which have taken ball or cigar shapes, a doughnut stabilizes persistent flows, because it would require too much energy for the central hole to drift about and disturb the rest of the condensate. These findings, to be published in *Physical Review Letters,* could yield deeper insights into superfluidity and also lead to especially precise navigation gyroscopes.



DOUGHNUT SPEEDWAY: Atoms move mostly in the red ring; they cannot climb the energy hill at the center.

The particles in ultracold solids may also be capable of frictionless flow, but some physicists have questioned whether past observations of such "supersolidity" were genuine. In the December 6, 2007, *Nature,* scientists reveal that solid helium becomes more rigid as the temperature drops closer to absolute zero. This phenomenon could have mimicked the effects of supersolidity in previous experiments—or it may indicate an entirely new property of supersolidity. Figuring out this mystery will take more experiments and cold logic. *—Charles Q. Choi*

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SciAm Perspectives

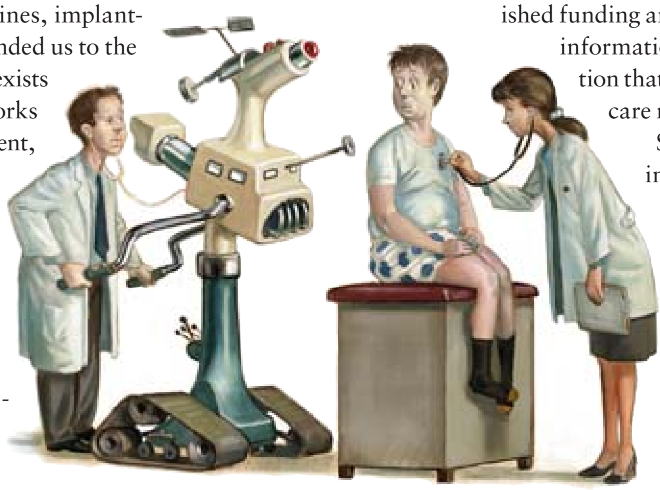
Pay for What Works

Presidential candidates must address unneeded medical technology and procedures as part of health care reform

BY THE EDITORS

The nation's 47 million uninsured are not the only reason that health care has become a big issue in the presidential campaigns. Besides leaving many uncovered, the U.S. also has trouble controlling the spending habits of a health care colossus that is on track to consume 20 cents of every dollar by 2015, a tripling from 1970 levels. Even back in 2005, the health expenditures for each U.S. citizen exceeded the entire per capita incomes of Chile or Venezuela.

The spending binge is rooted in the nation's technophilia: medical technology accounts for as much as half the growth in health care spending. Although this trend has benefited everyone—witness the near halving of cardiac arrest deaths from 1980 to 2000—not all those added dollars have been as well spent as drug and device manufacturers would have us believe. Our love affair with next-generation imaging machines, implantable devices and the like has blinded us to the reality that scant evidence often exists for whether something novel works any better than existing equipment, procedures or chemicals.



The recently published book *Overtreated* by New America Foundation Fellow Shannon Brownlee documents how surgical operations to relieve back pain, elective angioplasties that dilate partially obstructed coronary arteries, and superfluous computed tomography contribute to the $400 billion to $700 billion in medical care (out of a $2-trillion health care economy) that does not better our health. In 2005 the state of Ohio had more MRI scanners than did all of Canada, leading physicians in Toledo to joke about why cars passing by city hospitals don't swerve out of control because of strong magnetic fields. Yet studies have shown that imaging techniques such as MRI have not improved diagnosis as much as doctors and patients think they have.

Brownlee's book does not even touch on some ultrahigh tech, such as the University of Texas M. D. Anderson Cancer Center's $125-million proton-beam facility, replete with a physics-grade particle accelerator, that zaps tumors. Questions remain, however, about whether proton beams are more effective than another form of radiotherapy that M. D. Anderson already offers.

One solution, advocated by Brownlee and some other health policy analysts, is a rejuvenation of the Agency for Healthcare Research and Quality (AHRQ)—or the creation of an organization like it—that would compare different treatments (a mission not within the Food and Drug Administration's purview). It would be entrusted with comparing the benefits and risks of drugs, procedures and medical devices, while gauging any benefits against costs. The same Newt Gingrich–led Congress that eliminated the Office of Technology Assessment in 1995 almost did away with the AHRQ, which barely survived with diminished funding and powers: it now serves only as an information clearinghouse, not an organization that makes recommendations on Medicare reimbursement decisions.

Several Democratic candidates, including Senators Hillary Clinton and Barack Obama, have endorsed the need for institutes that would lay the foundation for "evidence-based" medicine. For a revitalized AHRQ or a clone thereof to work as it should will require that a new president follow through with adequate funding, an assurance that Medicare (and, as a consequence, other insurers) will consider seriously its findings and, perhaps most important, a Federal Reserve–like independence from the momentary whims of the political establishment. The original impetus to dismantle the AHRQ came after a group of outraged back surgeons objected to the agency's recommendation that surgery should not be tried before drugs and physical therapy. A watchdog that helps to ensure we pay only for what works, notwithstanding the entreaties of drug companies and equipment manufacturers to do the opposite, will provide a powerful brake on the spiraling costs already choking our medical system. ■

MATT COLLINS

Forum

Brazil's Option for Science Education

A new nationwide plan to enfranchise all citizens through education will allow Brazil to reach its full potential

BY LUIZ INÁCIO LULA DA SILVA, FERNANDO HADDAD AND MIGUEL A. L. NICOLELIS

Less than a quarter of a century after emerging from a military dictatorship, Brazilians have built a stable and vibrant democracy in which more than 80 million voters freely decide the future of their beloved country in each and every election. Lately, by becoming a world leader in food production, spearheading the search for biofuels as a new source of renewable energy and seeking ways to grow its economy while still protecting its unique natural ecosystems, Brazil has started to address a broad range of difficult and unavoidable issues that currently challenge most developing nations worldwide.

Brazil had to work arduously during the past decade to achieve its present economic stability and prosperity. Yet at this crucial juncture of its history, the country faces the daunting task of translating its political and economic stability into social policies and programs that can improve, at long last, the quality of life for millions of Brazilians who, until very recently, would have had no hope of sharing in the country's enormous wealth. But how do you empower millions of citizens, particularly young people, to become true participants in a global society that is continuously changing at a stunning pace as a result of the never-ending incorporation of new knowledge and technologies?

The answer is straightforward: systemic high-quality education, disseminated to reach the entire territory, including the most remote and impoverished communities of this vast country, so that all Brazilians can acquire the means to become creative and critical thinkers, capable of developing their own opinions and becoming true contributors to solve the challenges involved in constructing a fair and democratic society.

Three tenets serve as the main foundations of the Brazilian Plan for the Development of Education (PDE): systemic, territorial and empowering education. Enacted by the current administration, this plan outlines a broad range of executive measures aimed at rescuing the quality, reach and long-term impact of the Brazilian education system.

In addition to promoting actions to improve the basic training of teachers, to establish a national evaluation system, and to define the basis for a close collaboration between the federal government and the states and municipal authorities, the PDE provides, from its fourth year on, an extra 19 billion reals (US$10,633,535,000) earmarked for education.

The PDE also enacts new directives and guidelines for the creation of the Federal Institutes for Education, Science and Technology (IFET in Portuguese), which will result in the establishment of a network of 354 institutes dedicated to teaching science and technology to high schoolers and training thousands of new teachers in the public education system.

Inspired by the example set by Alberto Santos-Dumont, the great Brazilian inventor and aviator, who in 1901 became the first man to fly a controllable airship powered by an engine, a group of Brazilian scientists decided in 2003 to establish, in the city of Natal, in the northeast of Brazil, a research institute dedicated to using the production of state-of-the-art science as an agent of social and economic transformation for one of the least developed regions of the country [see "Building a Future on Science," by Christine Soares, on page 80]. Among its social initiatives, the Edmond and Lily Safra International Institute of Neuroscience of Natal (ELS-IINN) has established a science education program that today reaches 1,000 children enrolled in one of the poorest performing public education districts in Brazil.

By bringing their vision, efforts and experience together, the Brazilian government, through the Federal University of Rio Grande do Norte, and the ELS-IINN have partnered to establish the Natal Campus of the Brain and to use this multidisciplinary, scientific-social initiative to launch the Alberto Santos-Dumont Science Education Program for Children. The goal of this initiative is to enroll one million children from the public school system nationwide in the most comprehensive science and technology education program in Brazilian history.

By clearly choosing to disseminate high-quality education and science education in particular throughout its entire territory, Brazil is sending a loud message to its citizens and the global community that this giant of the tropics has finally awakened and is now ready to fulfill its potential as a true country of the future.

For Brazilians, a bright future starts now. ■

Luiz Inácio Lula da Silva (right) *is the president of Brazil. Fernando Haddad is Brazil's minister of education. Miguel A. L. Nicolelis is scientific coordinator of the ELS-IINN and co-director of the Center for Neuroengineering at Duke University.*

PHOTOGRAPH BY ERALDO PERES *AP Photo;* ILLUSTRATION BY MATT COLLINS

THE EDITORS' BLOG

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Are Quiet Electronics Robbing Us of Vital Information?

Posted by Christopher Mims, Oct. 4, 2007

Blind people are protesting superquiet hybrid Toyota Priuses, going so far as to use their national federation to request minimum noise levels for the vehicles so as to make them more "visible" to sight-impaired folk.

As electronics get quieter, we are losing vital information that tells us about their performance and status. For example:

1. In the old days, hard drives were so noisy you always knew when they were on. What's more, you could hear the read/write head actually reading and writing—vital information when trying to determine whether a computer is locked up or just slowed to a crawl.

2. Many mechanical devices, be they cars or water heaters, make consistent sounds that reassure us that they're in good working order—and alert us to malfunctions before they become obvious or lead to more substantial damage. I know when the compressor in my refrigerator has conked out because I can hear it.

As we move toward solid-state devices with fewer moving parts, we are going to have to develop new diagnostic systems to cope with their impending failure. It's a little like the malodorous smell of natural gas—that smell isn't natural at all; it's been added by the gas company to guarantee that you know when there's a leak. What's the 21st-century equivalent of that for cars and computers?

The Evolutionary Origins of the New York City Marathon

Posted by JR Minkel, Nov. 5, 2007

Yesterday was the New York City Marathon, the mecca of long-distance running, which drew more than 39,000 contestants and proved that birthing a child need not get in the way of a brisk 26.2-mile tromp through the streets of this fair city.

Why, oh, why do humans have such an itch to run? On one level, I'm sure it's cathartic to prove you can go that far without dying like that Greek chap did, and I'm sure there

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Sustainable Developments

Crisis in the Drylands

Sound economic solutions, not military ones, offer the most reliable route to peace for undeveloped nations

BY JEFFREY D. SACHS

BRUCE GILBERT/EARTH INSTITUTE

The vast region of deserts, grasslands and sparse woodlands that stretches across the Sahel, the Horn of Africa, the Middle East and Central Asia is by far the most crisis-ridden part of the planet. With the exception of a few highly affluent states in the Persian Gulf, these dryland countries face severe and intensifying challenges, including frequent and deadly droughts, encroaching deserts, burgeoning populations and extreme poverty. The region scores at the very bottom of the United Nations's Index of Human Development, which ranks countries according to their incomes, life expectancy and educational attainments.

As a result of these desperate conditions, the dryland countries are host to a disproportionate number of the world's violent conflicts. Look closely at the violence in Afghanistan, Chad, Ethiopia, Iraq, Pakistan, Somalia and Sudan—one finds tribal and often pastoralist communities struggling to survive deepening ecological crises. Water scarcity, in particular, has been a source of territorial conflict when traditional systems of land management fail in the face of rising populations and temperatures and declining rainfall.

Washington looks at many of these clashes and erroneously sees Islamist ideology at the core. Our political leaders fail to realize that other Islamic populations are far more stable economically, politically and socially—and that the root of the crisis in the dryland countries is not Islam but extreme poverty and environmental stress.

The Washington mind-set also prefers military approaches to developmental ones. The U.S. has supported the Ethiopian army in a military incursion into Somalia. It has pushed for military forces to stop the violence in Darfur. It has armed the clans in the deserts of western Iraq and now proposes to arm pastoralist clans in Pakistan along the Afghan border.

The trouble with the military approach is that it is extremely expensive and yet addresses none of the underlying problems. Indeed, the U.S. weapons provided to local clans often end up getting turned on the U.S. itself at a later date. Tellingly, one of the greatest obstacles to posting the proposed peacekeeping troops to Darfur is the lack of a water supply for them. Given the difficulty of finding water for those 26,000 soldiers, it becomes easier to understand the severity of the ongoing and unsolved water crisis facing the five million to seven million residents of Darfur.

> *Washington looks at these clashes and erroneously sees Islamist ideology at the core.*

Fortunately, much better solutions exist once the focus is put squarely on nurturing sustainable development. Today many proven techniques for "rainwater harvesting" can collect and store rain for later use by people, livestock and crops. In some areas, boreholes that tap underground aquifers can augment water availability; in others, rivers and seasonal surface runoff can be used for irrigation.

Such solutions may cost hundreds of dollars per household, spread out over a

few years. This outlay is far too much for the impoverished households to afford but far less than the costs to societies of conflicts and military interventions. The same is true for other low-cost interventions to fight diseases, provide schooling for children and ensure basic nutrition.

To end the poverty trap, pastoralists can increase the productivity of livestock through improved breeds, veterinary care and scientific management of fodder. Often pastoralists can multiply their incomes by selling whole animals, meat products, processed goods (such as leather) and dairy products. The wealthy states of the Middle East are a potentially lucrative nearby market for the livestock industries of Africa and Central Asia.

To build this export market, pastoralist economies will need help with all-weather roads, storage facilities, cell phone coverage, power, veterinary care and technical advice, to mention just a few of the key investments. With crucial support and active engagement of the private sector, however, impoverished dryland communities will be able to take advantage of transformative communications technologies and even gain access to capital from abroad.

MATT COLLINS

Today's dryland crises in Africa and Central Asia affect the entire world. The U.S. should rethink its overemphasis on military approaches, and Europe should honor its unmet commitments of aid to this region, but other nations—including the wealthy countries of the Middle East and new donors such as India and China—can also help turn the tide. The only reliable way to peace in the vast and troubled drylands will be through sustainable development. ■

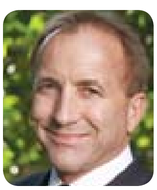
Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

Skeptic

The Mind of the Market

Evolutionary economics explains why irrational financial choices were once rational

BY MICHAEL SHERMER



BRAD SWONETZ

Because 99 percent of our evolutionary history was spent as hunter-gatherers living in small bands of a few dozen to a few hundred people, we evolved a psychology not always well equipped to reason our way around the modern world. What may seem like irrational behavior today may have actually been rational 100,000 years ago. Without an evolutionary perspective, the assumptions of *Homo economicus*—that "Economic Man" is rational, self-maximizing and efficient in making choices—make no sense. Take economic profit versus psychological fairness as an example.

Behavioral economists employ an experimental procedure called the Ultimatum Game. It goes something like this. You are given $100 to split between yourself and your game partner. Whatever division of the money you propose, if your partner accepts it, you are both richer by that amount. How much should you offer? Why not suggest a $90–$10 split? If your game partner is a rational, self-interested money maximizer, he isn't going to turn down a free 10 bucks, is he? He is. Research shows that proposals that deviate much beyond a $70–$30 split are usually rejected.

Why? Because they aren't fair. Says who? Says the moral emotion of "reciprocal altruism," which evolved over the Paleolithic eons to demand fairness on the part of our potential exchange partners. "I'll scratch your back if you'll scratch mine" only works if I know you will respond with something approaching parity. The moral sense of fairness is hardwired into our brains and is an emotion shared by most people and primates tested for it. Thousands of experimental trials with subjects from Western countries have consistently revealed a sense of injustice at low-ball offers. Further, we now have a sizable body of data from peoples in non-Western cultures around the world, including those living close to how our Paleolithic ancestors lived, and although their responses vary more than those of modern peoples living in market economies do, they still show a strong aversion to unfairness.

The deeper evolution of this phenomenon can be seen in the behavior of our primate cousins. In studies with both chimpanzees and capuchin monkeys, Emory University primatologists Frans de Waal and Sarah Brosnan found that when two individuals work together on a task for which only one is rewarded with a desired food, if the reward recipient does not share that food with his task partner, the

THE EDITORS' BLOG

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are hormones involved—runner's high and all that—but that's not what I mean. Like any science nerd, I cannot comprehend human behavior without help from an evolutionary just-so story, or plausible adaptive explanation, for how we could have evolved such an ability. Science be praised, there's a good adaptive hypothesis for running that sounds like it could even be true: hunting prey.

From a story last year in *Discover:*

"University of Utah biologist Dennis Bramble and Harvard University paleoanthropologist Daniel Lieberman … argue that not only can humans outlast horses, but over long distances and under the right conditions, they can also outrun just about any other animal on the planet—including dogs, wolves, hyenas, and antelope, the other great endurance runners. From our abundant sweat glands to our Achilles tendons, from our big knee joints to our muscular glutei maximi, human bodies are beautifully tuned running machines. 'We're loaded top to bottom with all these features, many of which don't have any role in walking,' Lieberman says."

And why would we have needed sustained speed? Why, to fuel our growing brains by catching prey rich in protein and fat, naturally. The obligatory anthrop evidence comes from run-alongs with Bushmen hunter-gatherers in the Kalahari Desert, who, after being sure to hydrate themselves properly like any good runner, chase prey to exhaustion, maintaining speeds for distances comparable to those of competitive marathoners.

The caveats (again from *Discover*):

"Functional morphologist Brigitte Demes, at the State University of New York at Stony Brook, notes that the gluteus maximus is absolutely essential for rising from a squatting posture at rest or during foraging, so it might not have evolved just for running. Stony Brook anatomist Jack Stern, famed for analyses of how Lucy walked, says it's a tough call to classify the Achilles tendon as an adaptation for jogging. Longer legs evolved in many animals through the extension of lightweight tendons rather than heavier muscle, thus producing a limb that took less effort to swing."

MATT COLLINS

partner will refuse to participate in future tasks and will express emotions that are clearly meant to convey displeasure at the injustice. In another experiment in which two capuchins were trained to exchange a granite stone for a cucumber slice, they made the trade 95 percent of the time. But if one monkey received a grape instead (a delicacy capuchins greatly prefer over cucumbers), the other monkey cooperated only 60 percent of the time, sometimes even refusing the cucumber slice altogether. In a third condition in which one monkey received a grape without even having to swap a granite stone for it, the other monkey cooperated only 20 percent of the time. And in several instances, they became so outraged at the inequity of the outcome they heaved the cucumber slice back at the human experimenters!

Such results suggest that all primates (including us) evolved a sense of justice, a moral emotion that signals to the individual that an exchange was fair or unfair. Fairness evolved as a stable strategy for maintaining social harmony in our ancestors' small bands, where cooperation was reinforced and became the rule while freeloading was punished and became the exception. What would appear to be irrational economic choices today—such as turning down a free $10 with a sense of righteous injustice—were, at one time, rational when seen through the lens of evolution.

Just as it is a myth that evolution is driven solely by "selfish genes" and that organisms are exclusively greedy, selfish and competitive, it is a myth that the economy is driven by people who are exclusively greedy, selfish and competitive. The fact is, we are equitably selfish and selfless, cooperative and competitive. There exists in both life and economies mutual struggle and mutual aid. In the main, however, the balance in our nature is heavily on the side of good over evil. Markets are moral, and modern economies are founded on our virtuous nature. The Gordon Gekko "Greed Is Good" model of business is the exception, and the Google Guys "Don't Be Evil" model of business is the rule. If this were not the case, market capitalism would have imploded long ago. ■

Michael Shermer is publisher of Skeptic *(www.skeptic.com). His new book is* The Mind of the Market.

Anti Gravity

Remembrance of Things Future

In 1900 the future looked bright and well ventilated

BY STEVE MIRSKY

It's well known that prediction is fraught with peril, especially when it's about the future. But if the future is past, then analyzing predictions about that past future is like an unwrapped present. (Tense yet?) A friend recently sent me an article from the December 1900 issue of the *Ladies' Home Journal*, in which one John Elfreth Watkins, Jr., listed a series of predictions for the year 2000. (See www.tinyurl.com/3yuaxx for the complete list.) Let's look at some of those prognostications now that 2000 is as gone as Watkins.

"There will probably be from 350,000,000 to 500,000,000 people in America." A bit on the high side of our current population of about 304 million. But not a bad estimate, especially given an American population in 1900 of a mere 76 million. Still, Watkins was way off the mark by then predicting that Nicaragua and Mexico would seek admission to the Union after the Panama Canal was finished. Actually, if Mexico did join the U.S. the fence some Americans want to build on the Latin American border could be reduced from about 2,000 miles down to only the approximately 400 border miles that Mexico shares with Guatemala and Belize. It's called thinking outside the boundaries.

"There will be no C, X or Q in our every-day alphabet. They will be abandoned because unnecessary." A quixotic notion.

"Mosquitoes, house-flies and roaches will have been practically exterminated." Unless "practically exterminated" meant pragmatically slamming a shoe heel on the insects, this one is obviously way off. As is:

"Rats and mice will have been exterminated." I didn't even kill the cartoon-cute little house mouse I found jumping around in my sink a few weeks ago. (I didn't let it move in with me rent-free either.) And if you're ever bored waiting for a New York City subway, you can pass the time playing find-the-rat-on-the-tracks. (Although somebody usually wins inside of 10 seconds.)

"Ready-cooked meals will be bought from establishments similar to our bakeries of to-day." Correct. "Food will be served hot or cold to private houses in pneumatic tubes or automobile wagons." Partly correct—hot food is delivered cold by automobile wagons. "The meal being over, the dishes used will be packed and returned to the cooking establishments where they will be washed." A bachelor's dream that is, alas, unrealized. Fortunately, in 1904 some genius invented the paper plate.

"There will be no street cars in our large cities." Mostly true, with the notable exceptions of San Francisco's trolleys and Boston's Green Line. Although anyone actually waiting for a Green Line train might indeed conclude that they no longer exist. "All hurry traffic will be below or high above ground when brought within city limits. In most cities it will be confined to broad subways or tunnels, well lighted and well ventilated." Granted, the lighting and ventilation are good enough to play find-the-rat-on-the-tracks. "Cities, therefore, will be free from all noises." Rendered erroneous by the then unforeseen invention of automobile sound systems with super bass subwoofers. And by legions of pedestrians yelling into cell phones.

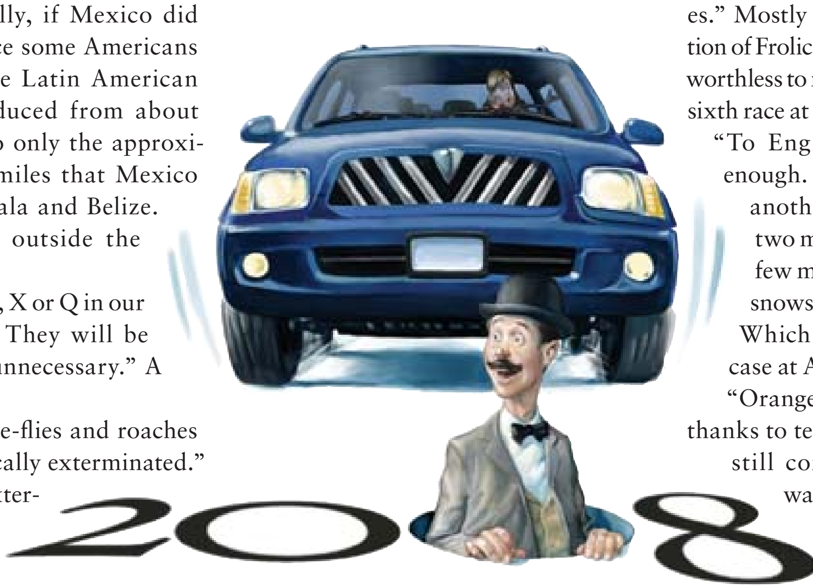
"The trip from suburban home to office will require a few minutes only. A penny will pay the fare." For two bucks, I can go the 12 miles between the Bronx and midtown Manhattan during the morning rush in only a little over an hour. ("Hurry traffic" is less a description than a fervent prayer.)

"Automobiles will be cheaper than horses." Mostly true, with the notable exception of Frolic N My Dreams, which became worthless to me by finishing dead last in the sixth race at Aqueduct on December 2.

"To England in two days." Close enough. Six hours for the flight, plus another two to get to the airport, two more in the security line, and a few more for flight delays. Unless it snows, in which case all bets are off. Which unfortunately was not the case at Aqueduct.

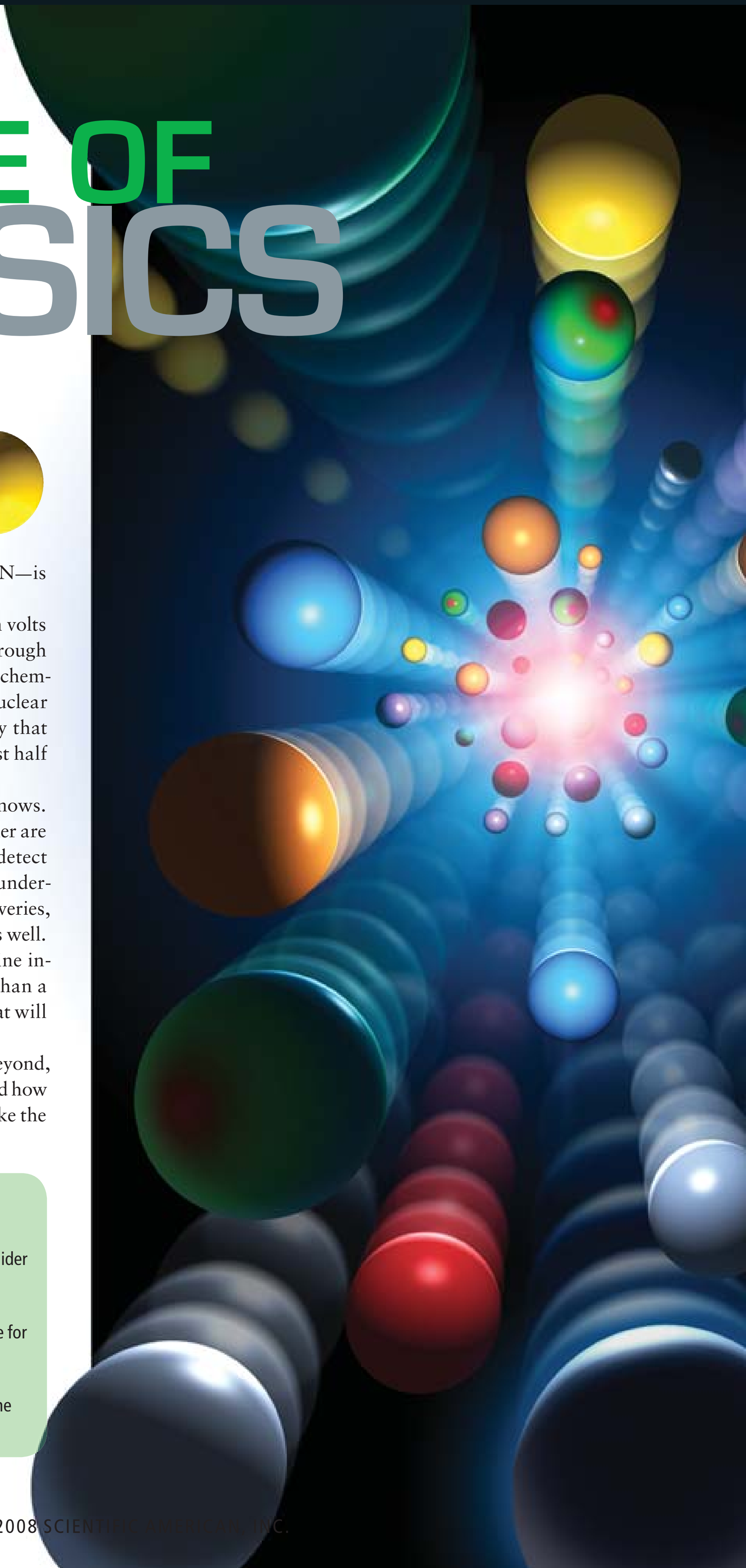
"Oranges will grow in Philadelphia," thanks to technology. Wrong, but might still come true, thanks to global warming.

"Everybody will walk ten miles." Eventually. ■



PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS

THE FUTURE OF PHYSICS



EDITORS' INTRODUCTION

They call it the terascale. It is the realm of physics that comes into view when two elementary particles smash together with a combined energy of around a trillion electron volts, or one tera-electron-volt. The machine that will take us to the terascale—the ring-shaped Large Hadron Collider (LHC) at CERN—is now nearing completion.

To ascend through the energy scales from electron volts to the terascale is to travel from the familiar world through a series of distinct landscapes: from the domains of chemistry and solid-state electronics (electron volts) to nuclear reactions (millions of electron volts) to the territory that particle physicists have been investigating for the past half a century (billions of electron volts).

What lies in wait for us at the terascale? No one knows.

But radically new phenomena of one kind or another are just about guaranteed to occur. Scientists hope to detect long-sought particles that could help complete our understanding of the nature of matter. More bizarre discoveries, such as signs of additional dimensions, may unfold as well.

Physicists are also drawing up plans for a machine intended to succeed and complement the LHC more than a decade hence, adding precision to the rough maps that will be deciphered from the LHC's data.

At the end of this "journey" to the terascale and beyond, we will for the first time know what we are made of and how the place where we briefly live operates at bottom. Like the completed LHC itself, we will have come full circle.

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CORNUCOPIA of familiar particles spraying out from each collision will include, just occasionally, something new and wonderful.

THE DISCOVERY MACHINE

A global collaboration of scientists is preparing to start up the greatest particle physics experiment in history **By Graham P. Collins**

You could think of it as the biggest, most powerful microscope in the history of science. The Large Hadron Collider (LHC), now being completed underneath a circle of countryside and villages a short drive from Geneva, will peer into the physics of the shortest distances (down to a *nano*-nanometer) and the highest energies ever probed. For a decade or more, particle physicists have been eagerly awaiting a chance to explore that domain, sometimes called the terascale because of the energy range involved: a trillion electron volts, or 1 TeV. Significant new physics is expected to occur at these energies, such as the elusive Higgs particle (believed to be responsible for imbuing other particles with mass) and the particle that constitutes the dark matter that makes up most of the material in the universe.

The mammoth machine, after a nine-year construction period, is scheduled (touch wood) to begin producing its beams of particles later this year. The commissioning process is planned to proceed from one beam to two beams to colliding beams; from lower energies to the terascale; from weaker test intensities to stronger ones suitable for producing data at useful rates but more difficult to control. Each step along the way will produce challenges to be overcome by the more than 5,000 scientists, engineers and students collaborating on the gargantuan effort. When I visited the project last fall to get a firsthand look at the preparations to probe the high-

SLIM FILMS

KEY CONCEPTS

- The Large Hadron Collider (LHC), the biggest and most complicated particle physics experiment ever seen, is nearing completion and is scheduled to start operating this year.
- The LHC will accelerate bunches of protons to the highest energies ever generated by a machine, colliding them head-on 30 million times a second, with each collision spewing out thousands of particles at nearly the speed of light.
- Physicists expect the LHC to bring about a new era of particle physics in which major conundrums about the composition of matter and energy in the universe will be resolved.

—The Editors

FAST FACTS

PROTON VELOCITY:
99.9999991% of light speed

PROTONS PER BUNCH:
up to 100 billion

NUMBER OF BUNCHES:
up to 2,808

BUNCH CROSSINGS PER SECOND:
up to 31 million, at 4 locations

COLLISIONS PER BUNCH CROSSING:
up to 20

DATA PER COLLISION:
about 1.5 megabytes

NUMBER OF HIGGS PARTICLES:
1 every 2.5 seconds (at full beam luminosity and under certain assumptions about the Higgs)

energy frontier, I found that everyone I spoke to expressed quiet confidence about their ultimate success, despite the repeatedly delayed schedule. The particle physics community is eagerly awaiting the first results from the LHC. Frank Wilczek of the Massachusetts Institute of Technology echoes a common sentiment when he speaks of the prospects for the LHC to produce "a golden age of physics."

A Machine of Superlatives

To break into the new territory that is the terascale, the LHC's basic parameters outdo those of previous colliders in almost every respect. It starts by producing proton beams of far higher energies than ever before. Its nearly 7,000 magnets, chilled by liquid helium to less than two kelvins to make them superconducting, will steer and focus two beams of protons traveling within a millionth of a percent of the speed of light. Each proton will have about 7 TeV of energy—7,000 times as much energy as a proton at rest has embodied in its mass, courtesy of Einstein's $E = mc^2$. That is about seven times the energy of the reigning record holder, the Tevatron collider at Fermi National Accelerator Laboratory in Batavia, Ill. Equally important, the machine is designed to produce beams with 40 times the intensity, or luminosity, of the Tevatron's beams. When it is fully loaded and at maximum energy, all the circulating particles will carry energy roughly equal to the kinetic energy of about 900 cars traveling at 100 kilometers per hour, or enough to heat the water for nearly 2,000 liters of coffee.

The protons will travel in nearly 3,000 bunches, spaced all around the 27-kilometer circumference of the collider. Each bunch of up to 100 billion protons will be the size of a needle, just a few centimeters long and squeezed down to 16 microns in diameter (about the same as the thinnest of human hairs) at the collision points. At four locations around the ring, these needles will pass through one another, producing more than 600 million particle collisions every second. The collisions, or events, as physicists call them, actually will occur between particles that make up the protons—quarks and gluons. The most cataclysmic of the smashups will release about a seventh of the energy available in the parent protons, or about 2 TeV. (For the same reason, the Tevatron falls short of exploring terascale physics by about a factor of five, despite the 1-TeV energy of its protons and antiprotons.)

Four giant detectors—the largest would roughly half-fill the Notre Dame cathedral in Paris, and the heaviest contains more iron than the Eiffel Tower—will track and measure the thousands of particles spewed out by each collision occurring at their centers. Despite the detectors' vast size, some elements of them must be positioned with a precision of 50 microns.

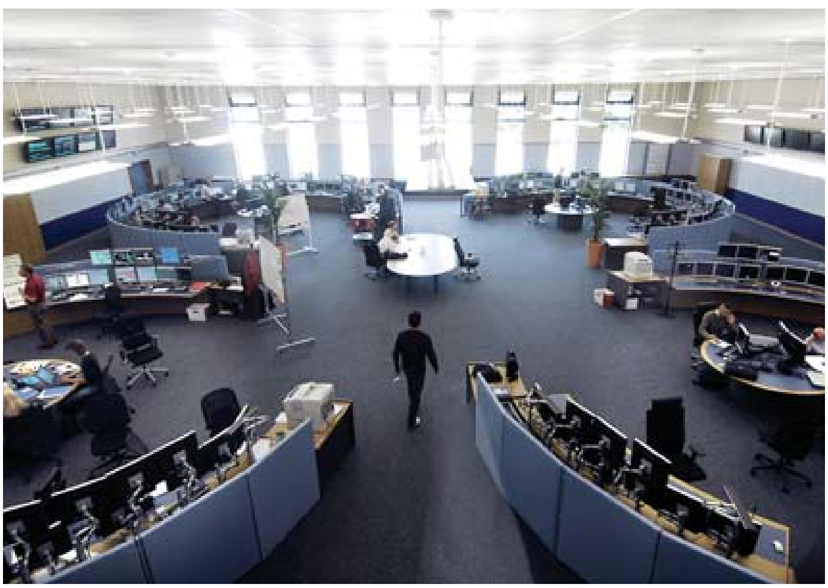
The nearly 100 million channels of data streaming from each of the two largest detectors would fill 100,000 CDs every second, enough to produce a stack to the moon in six months. So instead of attempting to record it all, the experiments will have what are called trigger and data-acquisition systems, which act like vast spam filters, immediately discarding almost all the information and sending the data from only the most promising-looking 100 events each second to the LHC's central computing system at CERN, the European laboratory for particle physics and the collider's home, for archiving and later analysis.

A "farm" of a few thousand computers at CERN will turn the filtered raw data into more compact data sets organized for physicists to comb through. Their analyses will take place on a so-called grid network comprising tens of thousands of PCs at institutes around the world, all connected to a hub of a dozen major centers on three continents that are in turn linked to CERN by dedicated optical cables.

Journey of a Thousand Steps

In the coming months, all eyes will be on the accelerator. The final connections between adjacent magnets in the ring were made in early

CONTROL of the LHC accelerator will be conducted from one section (*lower right*) of the CERN control center. The detectors have their own control rooms.



FRED MERZ *Rezo*

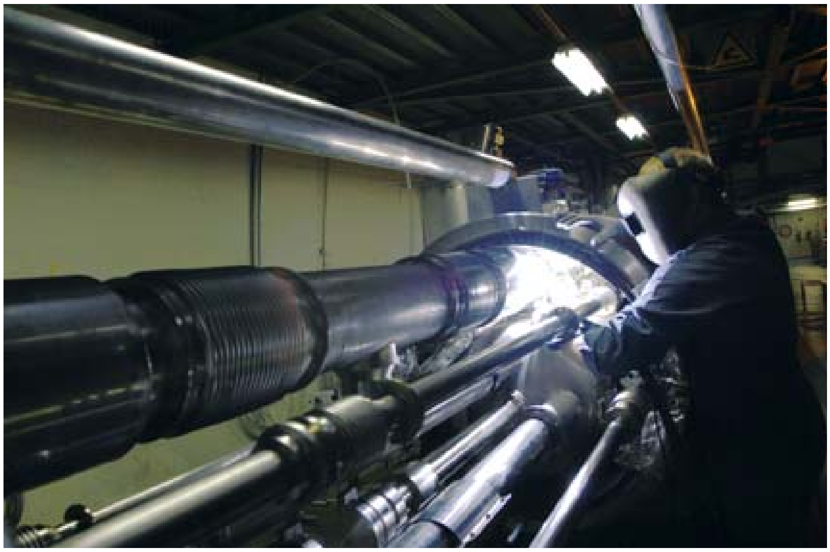
November, and as we go to press in mid-December one of the eight sectors has been cooled almost to the cryogenic temperature required for operation, and the cooling of a second has begun. One sector was cooled, powered up and then returned to room temperature earlier in 2007. After the operation of the sectors has been tested, first individually and then together as an integrated system, a beam of protons will be injected into one of the two beam pipes that carry them around the machine's 27 kilometers.

The series of smaller accelerators that supply the beam to the main LHC ring has already been checked out, bringing protons with an energy of 0.45 TeV "to the doorstep" of where they will be injected into the LHC. The first injection of the beam will be a critical step, and the LHC scientists will start with a low-intensity beam to reduce the risk of damaging LHC hardware. Only when they have carefully assessed how that "pilot" beam responds inside the LHC and have made fine corrections to the steering magnetic fields will they proceed to higher intensities. For the first running at the design energy of 7 TeV, only a single bunch of protons will circulate in each direction instead of the nearly 3,000 that constitute the ultimate goal.

As the full commissioning of the accelerator proceeds in this measured step-by-step fashion, problems are sure to arise. The big unknown is how long the engineers and scientists will take to overcome each challenge. If a sector has to be brought back to room temperature for repairs, it will add months.

The four experiments—ATLAS, ALICE, CMS and LHCb—also have a lengthy process of completion ahead of them, and they must be closed up before the beam commissioning begins. Some extremely fragile units are still being installed, such as the so-called vertex locator detector that was positioned in LHCb in mid-November. During my visit, as one who specialized in theoretical rather than experimental physics many years ago in graduate school, I was struck by the thick rivers of thousands of cables required to carry all the channels of data from the detectors—every cable individually labeled and needing to be painstakingly matched up to the correct socket and tested by present-day students.

Although colliding beams are still months in the future, some of the students and postdocs already have their hands on real data, courtesy of cosmic rays sleeting down through the Franco-Swiss rock and passing through their detectors sporadically. Seeing how the detectors respond to these interlopers provides an important reality check that everything is working together correctly—from the voltage supplies to the detector elements themselves to the electronics of the readouts to the data-acquisition software that integrates the millions of individual signals into a coherent description of an "event."



FRANÇOIS WAVRE *Rezo*

MAGNET REPAIRS had to be carried out in 2007 after a design flaw came to light during a stress test.

All Together Now

When everything *is* working together, including the beams colliding at the center of each detector, the task faced by the detectors and the data-processing systems will be Herculean. At the design luminosity, as many as 20 events will occur with each crossing of the needlelike bunches of protons. A mere 25 nanoseconds pass between one crossing and the next (some have larger gaps). Product particles sprayed out from the collisions of one crossing will still be moving through the outer layers of a detector when the next crossing is already taking place. Individual elements in each of the detector layers respond as a particle of the right kind passes through it. The millions of channels of data streaming away from the detector produce about a megabyte of data from each event: a petabyte, or a billion megabytes, of it every two seconds.

The trigger system that will reduce this flood of data to manageable proportions has multiple levels. The first level will receive and analyze data from only a subset of all the detector's components, from which it can pick out promising events based on isolated factors such as whether an energetic muon was spotted flying out at a large angle from the beam axis. This so-called level-one triggering will be conducted by hundreds of dedicated computer boards—the logic

CURIOSITIES

TILT!

The LHC's tunnel is tilted 1.4 percent from horizontal, to put as much of it as possible inside solid rock. It is about 50 meters deep on the Lake Geneva side and 175 meters deep on the other.

PHASES OF THE MOON

When the moon is full, at "high tide" the land near Geneva rises 25 centimeters, the LHC's circumference increases by 1 millimeter, and the beam energy changes by 0.02 percent. The experimenters must allow for this effect: they must know the beam energy to within 0.002 percent accuracy.

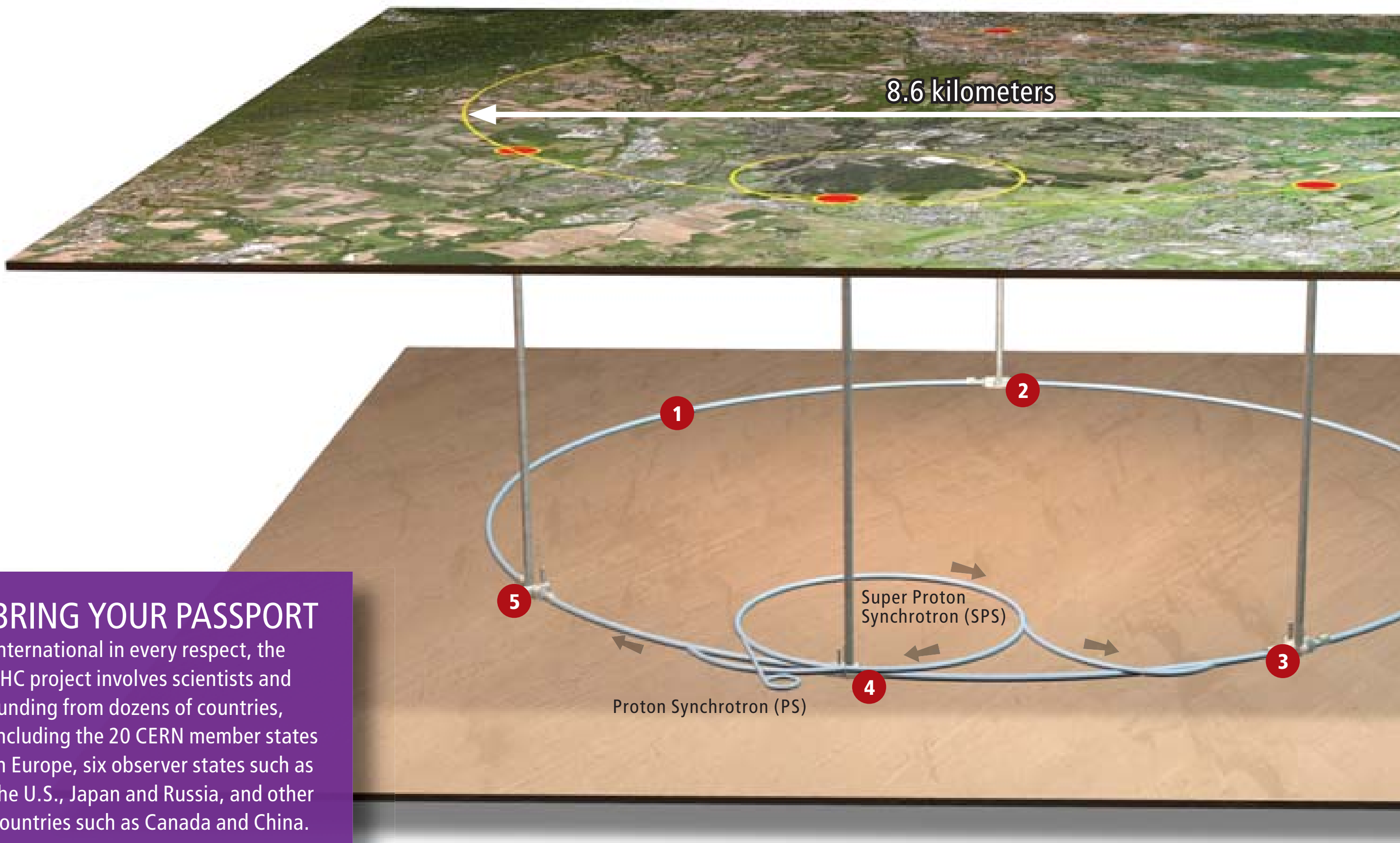
THE OCTAGON

The LHC tunnel is actually octagonal, with eight arcs connected by eight short, straight sections that harbor the four experiments and facilities related to controlling the beam.

[LHC AT A GLANCE]

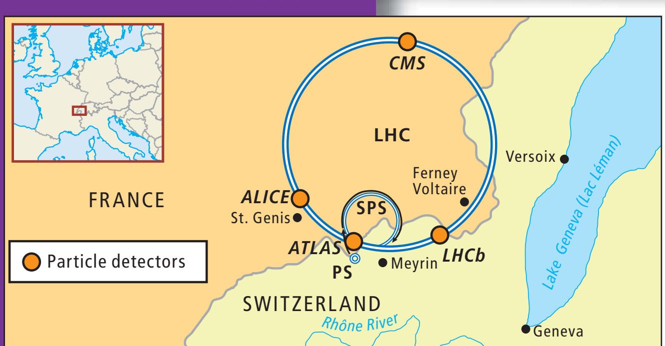
One Ring to Rule Them All

The Large Hadron Collider combines trusty old workhorses and trailblazing behemoths. Decades-old accelerators, including the Proton Synchrotron and the Super Proton Synchrotron, get the protons to 99.99975 percent of light speed. The LHC boosts the protons' energy by nearly 16 times and collides them 30 million times a second for up to 10 hours. Four major experiments generate more than 100 terabytes of collision data per second.



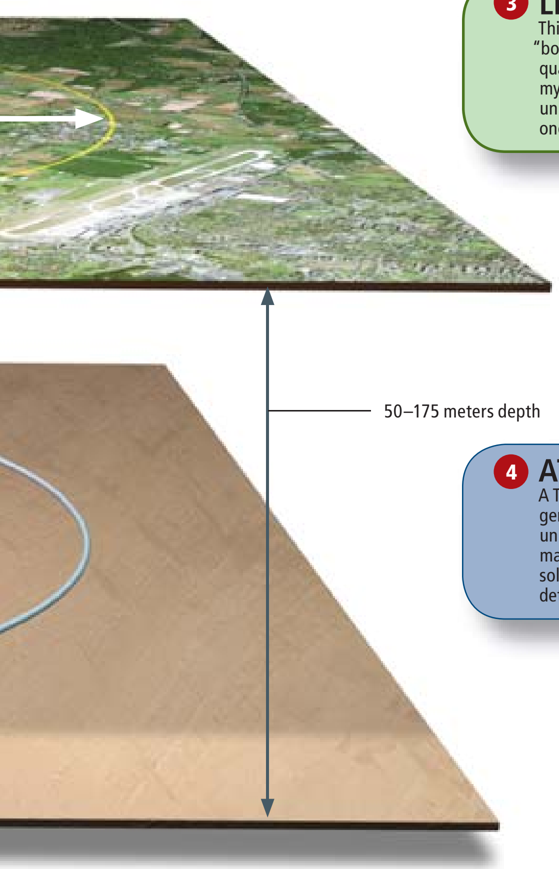
BRING YOUR PASSPORT

International in every respect, the LHC project involves scientists and funding from dozens of countries, including the 20 CERN member states in Europe, six observer states such as the U.S., Japan and Russia, and other countries such as Canada and China.

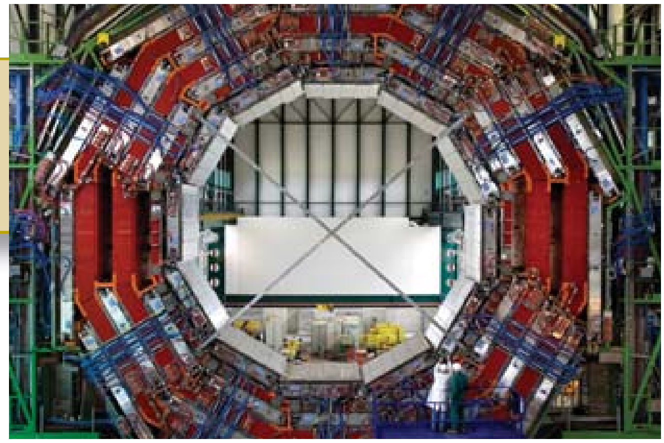


DON FOLEY (*illustration*); CERN (*aerial image*); SIMON NORFOLK *NB Pictures/Contact Press Images* (*LHC tunnel*); STEFANO DAL POZZOLO *Contrasto/Redux* (*CMS* and *ATLAS*); CERN GENEVA (*LHCb* and *ALICE*); MAPPING SPECIALISTS (*map*)

1 LHC ACCELERATOR
Nearly 7,000 superconducting magnets steer the proton beams around the tunnel that was dug for the Large Electron Positron (LEP) collider in 1989 and focuses them to a hair's breadth.

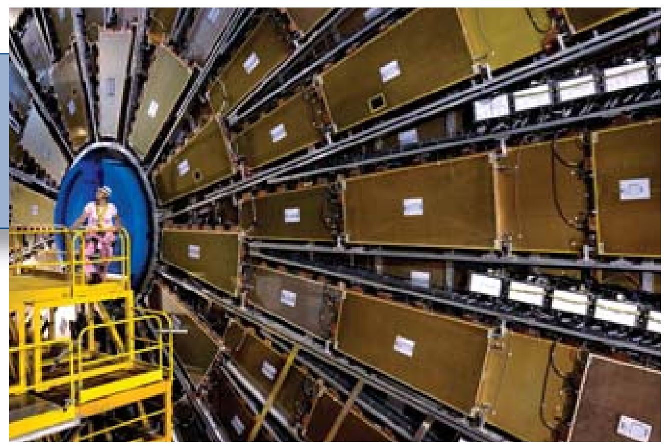


2 CMS
The Compact Muon Solenoid is one of two huge general purpose detectors that will lead the search for particles such as the Higgs and other new phenomena. It has five "barrel wheels" like the one shown here as well as end caps.

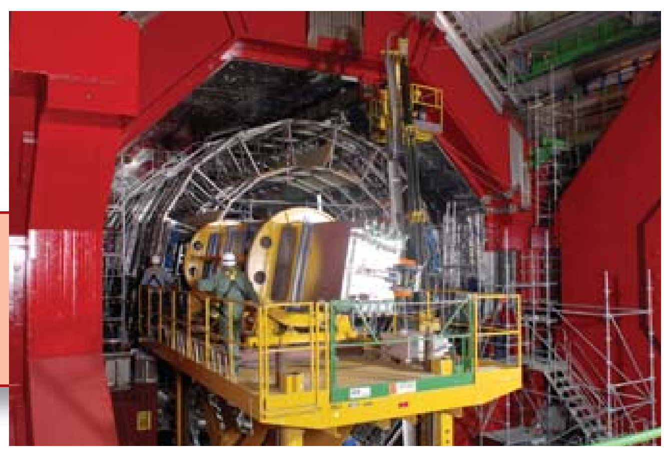


3 LHCb
This detector looks for "beauty" (or "bottom") flavored quarks and antiquarks, to understand how the mysterious absence of antimatter in the universe came about. It monitors only one side of its collision point.

4 ATLAS
A Toroidal LHC Apparatus is the other general purpose detector, with a unique design based on toroidal magnets instead of the traditional solenoid. The "big wheels" (*right*) detect key particles called muons.



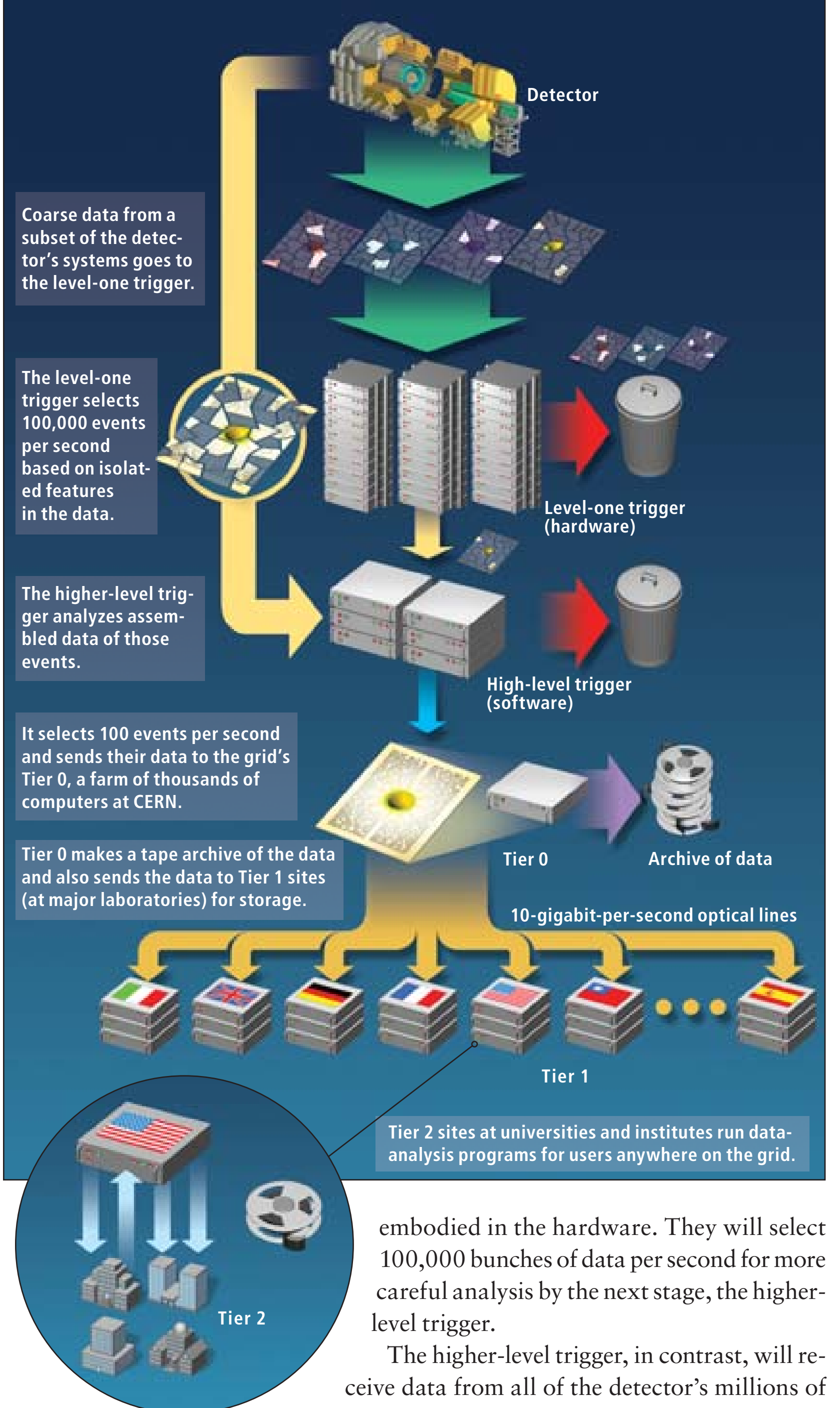
5 ALICE
A Large Ion Collider Experiment studies collisions of lead (Pb) ions producing primordial fireballs called the quark-gluon plasma. It also studies the proton-proton collisions as a reference point.



[DATA HANDLING]

TOO MUCH INFORMATION

With up to 20 collisions occurring at 25-nanosecond intervals at the center of each detector, the LHC produces more data than can be recorded. So-called trigger systems select the tiny fraction of the data that has promising features and discard the rest. A global network of computers called a grid provides thousands of researchers around the world with access to the stored data and the processing power to analyze it.



embodied in the hardware. They will select 100,000 bunches of data per second for more careful analysis by the next stage, the higher-level trigger.

The higher-level trigger, in contrast, will receive data from all of the detector's millions of channels. Its software will run on a farm of computers, and with an average of 10 microseconds elapsing between each bunch approved by the level-one trigger, it will have enough time to "reconstruct" each event. In other words, it will project tracks back to common points of origin and thereby form a coherent set of data—energies, momenta, trajectories, and so on—for the particles produced by each event.

The higher-level trigger passes about 100 events per second to the hub of the LHC's global network of computing resources—the LHC Computing Grid. A grid system combines the processing power of a network of computing centers and makes it available to users who may log in to the grid from their home institutes [see "The Grid: Computing without Bounds," by Ian Foster; Scientific American, April 2003].

The LHC's grid is organized into tiers. Tier 0 is at CERN itself and consists in large part of thousands of commercially bought computer processors, both PC-style boxes and, more recently, "blade" systems similar in dimensions to a pizza box but in stylish black, stacked in row after row of shelves [*see illustration on opposite page*]. Computers are still being purchased and added to the system. Much like a home user, the people in charge look for the ever moving sweet spot of most bang for the buck, avoiding the newest and most powerful models in favor of more economical options.

The data passed to Tier 0 by the four LHC experiments' data-acquisition systems will be archived on magnetic tape. That may sound old-fashioned and low-tech in this age of DVD-RAM disks and flash drives, but François Grey of the CERN Computing Center says it turns out to be the most cost-effective and secure approach.

Tier 0 will distribute the data to the 12 Tier 1 centers, which are located at CERN itself and at 11 other major institutes around the world, including Fermilab and Brookhaven National Laboratory in the U.S., as well as centers in Europe, Asia and Canada. Thus, the unprocessed data will exist in two copies, one at CERN and one divided up around the world. Each of the Tier 1 centers will also host a complete set of the data in a compact form structured for physicists to carry out many of their analyses.

The full LHC Computing Grid also has Tier 2 centers, which are smaller computing centers at universities and research institutes. Computers at these centers will supply distributed processing power to the entire grid for the data analyses.

Rocky Road

With all the novel technologies being prepared to come online, it is not surprising that the LHC has experienced some hiccups—and some more

SLIM FILMS

serious setbacks—along the way. Last March a magnet of the kind used to focus the proton beams just ahead of a collision point (called a quadrupole magnet) suffered a "serious failure" during a test of its ability to stand up against the kind of significant forces that could occur if, for instance, the magnet's coils lost their superconductivity during operation of the beam (a mishap called quenching). Part of the supports of the magnet had collapsed under the pressure of the test, producing a loud bang like an explosion and releasing helium gas. (Incidentally, when workers or visiting journalists go into the tunnel, they carry small emergency breathing apparatuses as a safety precaution.)

These magnets come in groups of three, to squeeze the beam first from side to side, then in the vertical direction, and finally again side to side, a sequence that brings the beam to a sharp focus. The LHC uses 24 of them, one triplet on each side of the four interaction points. At first the LHC scientists did not know if all 24 would need to be removed from the machine and brought aboveground for modification, a time-consuming procedure that could have added weeks to the schedule. The problem was a design flaw: the magnet designers (researchers at Fermilab) had failed to take account of all the kinds of forces the magnets had to withstand. CERN and Fermilab researchers worked feverishly, identifying the problem and coming up with a strategy to fix the undamaged magnets in the accelerator tunnel. (The triplet damaged in the test was moved aboveground for its repairs.)

In June, CERN director general Robert Aymar announced that because of the magnet failure, along with an accumulation of minor problems, he had to postpone the scheduled start-up of the accelerator from November 2007 to spring of this year. The beam energy is to be ramped up faster to try to stay on schedule for "doing physics" by July.

Although some workers on the detectors hinted to me that they were happy to have more time, the seemingly ever receding start-up date is a concern because the longer the LHC takes to begin producing sizable quantities of data, the more opportunity the Tevatron has—it is still running—to scoop it. The Tevatron could find evidence of the Higgs boson or something equally exciting if nature has played a cruel trick and given it just enough mass for it to show up only now in Fermilab's growing mountain of data.

Holdups also can cause personal woes through the price individual students and scientists pay as they delay stages of their careers waiting for data.

Another potentially serious problem came to light in September, when engineers discovered that sliding copper fingers inside the beam pipes known as plug-in modules had crumpled after a sector of the accelerator had been cooled to the cryogenic temperatures required for operation and then warmed back to room temperature.

At first the extent of the problem was unknown. The full sector where the cooling test had been conducted has 366 plug-in modules, and opening up every one for inspection and possibly repair would have been terrible. Instead the team addressing the issue devised a scheme to insert a ball slightly smaller than a Ping-Pong ball into the beam pipe—just small enough to fit and be blown along the pipe with compressed air and large enough to be stopped at a deformed module. The sphere contained a radio transmitting at 40 megahertz—the same frequency at which bunches of protons will travel along the pipe when the accelerator is running at full capacity—enabling the tracking of its progress by beam sensors that are installed every 50 meters. To everyone's relief, this procedure revealed that only six of the sector's modules had malfunctioned, a manageable number to open up and repair.

When the last of the connections between accelerating magnets was made in November, completing the circle and clearing the way to start cooling down all the sectors, project leader Lyn Evans commented, "For a machine of this complexity, things are going remarkably smoothly, and we're all looking forward to doing physics with the LHC next summer." ■

THOUSANDS of processors at CERN are linked together to provide the computing power needed to manage the data as they flow from the experiments.

FRED MERZ *Rezo*

➥ MORE TO EXPLORE

The Large Hadron Collider. Chris Llewellyn Smith in *Scientific American,* Vol. 283, No. 1; pages 70–77; July 2000.

Discovering the Quantum Universe. Available at **www.interactions.org/quantumuniverse/qu2006**

CERN's pages for the public are at **http://public.web.cern.ch/public**

Links to the LHC experiments are at **http://lhc.web.cern.ch/lhc/LHC_Experiments.htm**

US LHC Blogs. Monica Dunford, Pamela Klabbers, Steve Nahn and Peter Steinberg. Available at **www.uslhc.us/blogs**

Track the daily status of the accelerator commissioning at **http://lhc.web.cern.ch/lhc**

THE COMING REVOLUTIONS IN PARTICLE PHYSICS

The current Standard Model of particle physics begins to unravel when probed much beyond the range of current particle accelerators. So no matter what the Large Hadron Collider finds, it is going to take physics into new territory **By Chris Quigg**

KEY CONCEPTS

- The Large Hadron Collider (LHC) is certain to find *something* new and provocative as it presses into unexplored territory.
- The Standard Model of particle physics requires a particle known as the Higgs boson, or a stand-in to play its role, at energies probed by the LHC. The Higgs, in turn, poses deep questions of its own, whose answers should be found in the same energy range.
- These phenomena revolve around the question of symmetry. Symmetries underlie the interactions of the Standard Model but are not always reflected in the operation of the model. Understanding why not is a key question.

—The Editors

When physicists are forced to give a single-word answer to the question of why we are building the Large Hadron Collider (LHC), we usually reply "Higgs." The Higgs particle—the last remaining undiscovered piece of our current theory of matter—is the marquee attraction. But the full story is much more interesting. The new collider provides the greatest leap in capability of any instrument in the history of particle physics. We do not know what it will find, but the discoveries we make and the new puzzles we encounter are certain to change the face of particle physics and to echo through neighboring sciences.

In this new world, we expect to learn what distinguishes two of the forces of nature—electromagnetism and the weak interactions—with broad implications for our conception of the everyday world. We will gain a new understanding of simple and profound questions: Why are there atoms? Why chemistry? What makes stable structures possible?

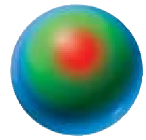
The search for the Higgs particle is a pivotal step, but only the first step. Beyond it lie phenomena that may clarify why gravity is so much weaker than the other forces of nature and that could reveal what the unknown dark matter that fills the universe is. Even deeper lies the prospect of insights into the different forms of matter, the unity of outwardly distinct particle categories and the nature of spacetime. The questions in play all seem linked to one another and to the knot of problems that motivated the prediction of the Higgs particle to begin with. The LHC will help us refine these questions and will set us on the road to answering them.

The Matter at Hand

What physicists call the "Standard Model" of particle physics, to indicate that it is still a work in progress, can explain much about the known world. The main elements of the Standard Model fell into place during the heady days of the 1970s and 1980s, when waves of landmark experimental discoveries engaged emerging theoretical ideas in productive conversation. Many particle physicists look on the past 15 years as an era of consolidation in contrast to the ferment of earlier decades. Yet even as the Standard Model has gained ever more experimental support, a growing list of phenomena lies outside its purview, and new theoretical ideas have expanded our conception of what a richer and more comprehensive worldview might look like. Taken together, the continuing progress in experiment and theory point to a very lively decade ahead. Perhaps we will look back and see that revolution had been brewing all along.

Our current conception of matter comprises two main particle categories, quarks and leptons, together with three of the four known fundamental forces, electromagnetism and the strong and weak interactions [*see box on page 48*]. Gravity is, for the moment, left to the side. Quarks, which make up protons and neutrons, generate and feel all three forces. Leptons, the best known of which is the electron, are immune to the strong force. What distinguishes these two categories is a property akin to electric charge, called color. (This name is metaphorical; it has nothing to do with ordinary colors.) Quarks have color, and leptons do not.

The guiding principle of the Standard Model



STUDYING THE WORLD with a resolution a billion times finer than atomic scales, particle physicists seek a deeper understanding of the everyday world and of the evolution of the universe.

is that its equations are symmetrical. Just as a sphere looks the same whatever your viewing angle is, the equations remain unchanged even when you change the perspective from which they are defined. Moreover, they remain unchanged even when the perspective shifts by different amounts at different points in space and time.

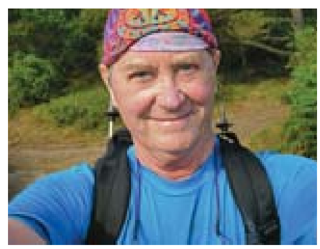
Ensuring the symmetry of a geometric object places very tight constraints on its shape. A sphere with a bump no longer looks the same from every angle. Likewise, the symmetry of the equations places very tight constraints on them. These symmetries beget forces that are carried by special particles called bosons [see "Gauge Theories of the Forces between Elementary Particles," by Gerard 't Hooft; Scientific American, June 1980, and "Elementary Particles and Forces," by Chris Quigg; Scientific American, April 1985].

In this way, the Standard Model inverts Louis Sullivan's architectural dictum: instead of "form follows function," function follows form. That is, the form of the theory, expressed in the symmetry of the equations that define it, dictates the function—the interactions among particles—that the theory describes. For instance, the strong nuclear force follows from the requirement that the equations describing quarks must be the same no matter how one chooses to define quark colors (and even if this convention is set independently at each point in space and time). The strong force is carried by eight particles known as gluons. The other two forces, electromagnetism and the weak nuclear force, fall under the rubric of the "electroweak" forces and are based on a different symmetry. The electroweak forces are carried by a quartet of particles: the photon, *Z* boson, W^+ boson and W^- boson.

Breaking the Mirror

The theory of the electroweak forces was formulated by Sheldon Glashow, Steven Weinberg and Abdus Salam, who won the 1979 Nobel Prize in Physics for their efforts. The weak force, which is involved in radioactive beta decay, does not act on all the quarks and leptons. Each of these particles comes in mirror-image varieties, termed left-handed and right-handed, and the beta-decay

[THE AUTHOR]



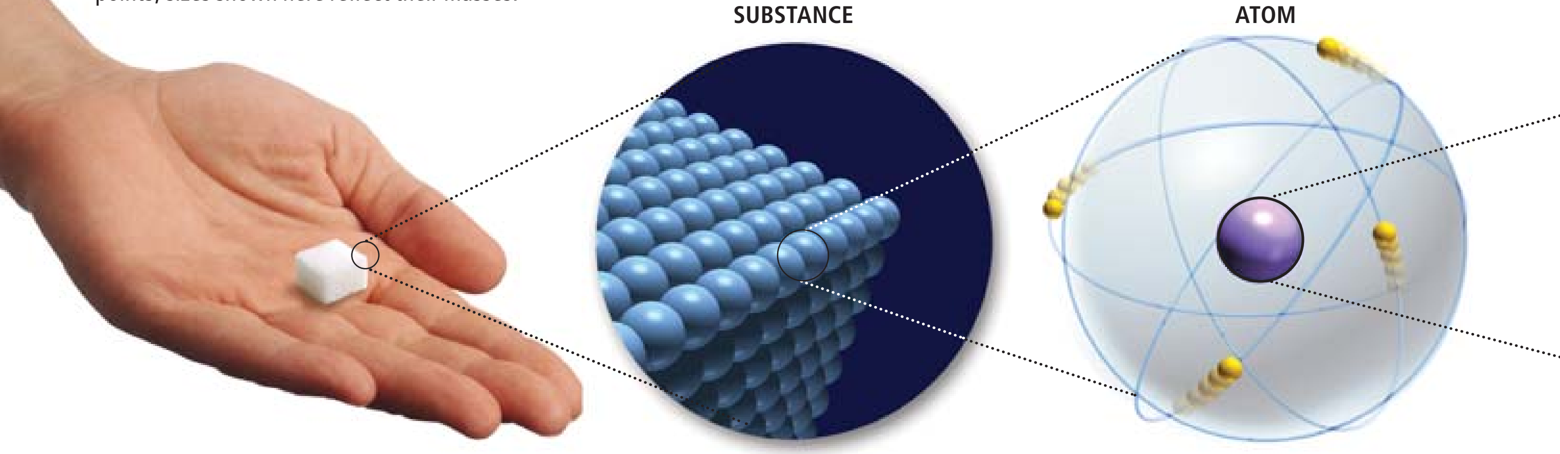
Chris Quigg is a senior scientist at Fermi National Accelerator Laboratory, where for 10 years he led the theoretical physics department. He is the author of a celebrated textbook on the so-called gauge theories that underlie the Standard Model, as well as the former editor of the *Annual Review of Nuclear and Particle Science.* Quigg's research on electroweak symmetry breaking and supercollider physics highlighted the importance of the terascale. He is a frequent visitor to CERN. When not blazing the trail to the deepest workings of nature, he can be found hiking on one of France's *Sentiers de Grande Randonnée.*

KENN BROWN (*Vitruvian man*); COURTESY OF CHRIS QUIGG (*Quigg*)

[THE BASICS OF PARTICLE PHYSICS]

What Really Matters

If you look deep inside a lump of matter, it is made up of only a few types of elementary particles, drawn from a palette of a dozen flavors. The Standard Model treats the particles as geometrical points; sizes shown here reflect their masses.



PARTICLES OF MATTER

QUARKS

These particles make up protons, neutrons and a veritable zoo of lesser-known particles. They have never been observed in isolation.

UP — u

Electric charge: $+^2/_3$
Mass: 2 MeV
Constituent of ordinary matter; two up quarks, plus a down, make up a proton.

CHARM — c

Electric charge: $+^2/_3$
Mass: 1.25 GeV
Unstable heavier cousin of the up; constituent of the J/ψ particle, which helped physicists develop the Standard Model.

TOP — t

Electric charge: $+^2/_3$
Mass: 171 GeV
Heaviest known particle, comparable in mass to an atom of osmium. Very short-lived.

DOWN — d

Electric charge: $-^1/_3$
Mass: 5 MeV
Constituent of ordinary matter; two down quarks, plus an up, compose a neutron.

STRANGE — s

Electric charge: $-^1/_3$
Mass: 95 MeV
Unstable heavier cousin of the down; constituent of the much studied kaon particle.

BOTTOM — b

Electric charge: $-^1/_3$
Mass: 4.2 GeV
Unstable and still heavier copy of the down; constituent of the much studied B-meson particle.

LEPTONS

These particles are immune to the strong force and are observed as isolated individuals. Each neutrino shown here is actually a mixture of neutrino species, each of which has a definite mass of no more than a few eV.

ELECTRON NEUTRINO — ν_e

Electric charge: 0
Immune to both electromagnetism and the strong force, it barely interacts at all but is essential to radioactivity.

MUON NEUTRINO — ν_μ

Electric charge: 0
Appears in weak reactions involving the muon.

TAU NEUTRINO — ν_τ

Electric charge: 0
Appears in weak reactions involving the tau lepton.

ELECTRON — e

Electric charge: –1
Mass: 0.511 MeV
The lightest charged particle, familiar as the carrier of electric currents and the particles orbiting atomic nuclei.

MUON — μ

Electric charge: –1
Mass: 106 MeV
A heavier version of the electron, with a lifetime of 2.2 microseconds; discovered as a component of cosmic-ray showers.

TAU — τ

Electric charge: –1
Mass: 1.78 GeV
Another unstable and still heavier version of the electron, with a lifetime of 0.3 picosecond.

PARTICLES OF FORCE

BOSONS

At the quantum level, each force of nature is transmitted by a dedicated particle or set of particles.

PHOTON — γ

Electric charge: 0
Mass: 0
Carrier of electromagnetism, the quantum of light acts on electrically charged particles. It acts over unlimited distances.

Z BOSON — Z

Electric charge: 0
Mass: 91 GeV
Mediator of weak reactions that do not change the identity of particles. Its range is only about 10^{-18} meter.

W^+/W^- BOSONS — W

Electric charge: +1 or –1
Mass: 80.4 GeV
Mediators of weak reactions that change particle flavor and charge. Their range is only about 10^{-18} meter.

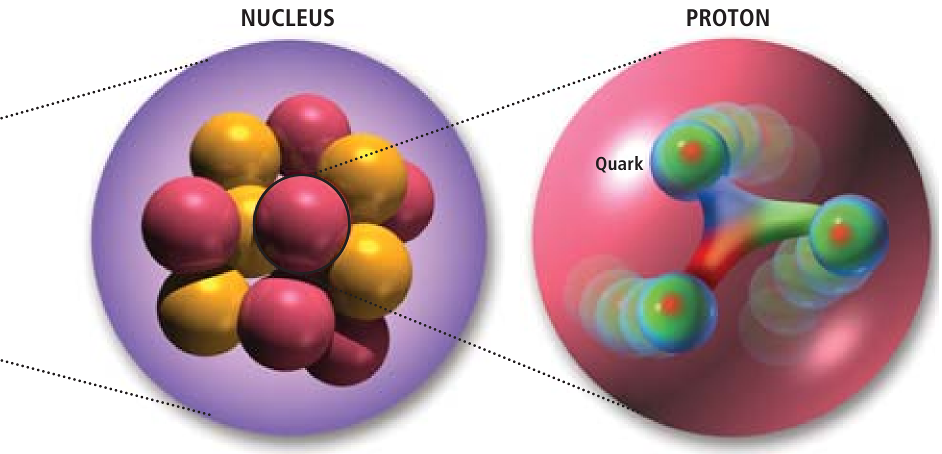
GLUONS — g

Electric charge: 0
Mass: 0
Eight species of gluons carry the strong interaction, acting on quarks and on other gluons. They do not feel electromagnetic or weak interactions.

HIGGS (not yet observed) — H

Electric charge: 0
Mass: Expected below 1 TeV, most likely between 114 and 192 GeV.
Believed to endow *W* and *Z* bosons, quarks and leptons with mass.

SLIM FILMS

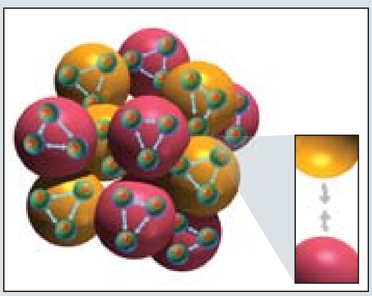


HOW THE FORCES ACT

An interaction among several colliding particles can change their energy, momentum or type. An interaction can even cause a single particle in isolation to decay spontaneously.

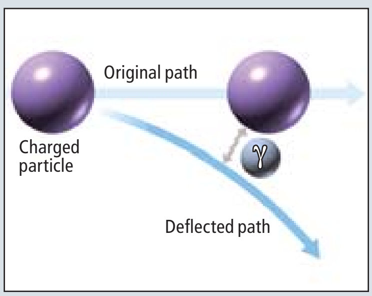
STRONG INTERACTION

The strong force acts on quarks and gluons. It binds them together to form protons, neutrons and more. Indirectly, it also binds protons and neutrons into atomic nuclei.



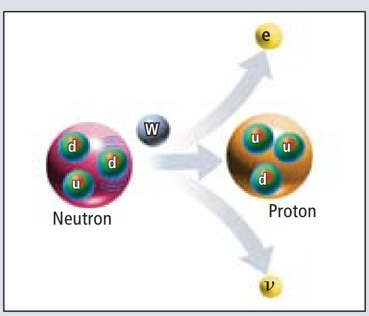
ELECTROMAGNETIC INTERACTION

The electromagnetic interaction acts on charged particles, leaving the particles unchanged. It causes like-charged particles to repel.



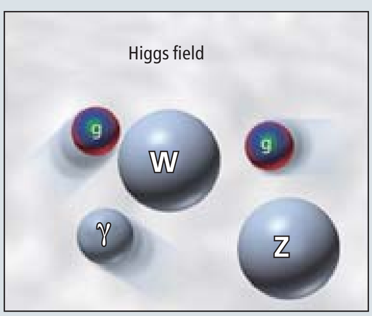
WEAK INTERACTION

The weak interaction acts on quarks and leptons. Its best-known effect is to transmute a down quark into an up quark, which in turn causes a neutron to become a proton plus an electron and a neutrino.



HIGGS INTERACTION

The Higgs field (*gray background*) is thought to fill space like a fluid, impeding the *W* and *Z* bosons and thereby limiting the range of weak interactions. The Higgs also interacts with quarks and leptons, endowing them with mass.



force acts only on the left-handed ones—a striking fact still unexplained 50 years after its discovery. The family symmetry among the left-handed particles helps to define the electroweak theory.

In the initial stages of its construction, the theory had two essential shortcomings. First, it foresaw four long-range force particles—referred to as gauge bosons—whereas nature has but one: the photon. The other three have a short range, less than about 10^{-17} meter, less than 1 percent of the proton's radius. According to Heisenberg's uncertainty principle, this limited range implies that the force particles must have a mass approaching 100 billion electron volts (GeV). The second shortcoming is that the family symmetry does not permit masses for the quarks and leptons, yet these particles do have mass.

The way out of this unsatisfactory situation is to recognize that a symmetry of the laws of nature need not be reflected in the outcome of those laws. Physicists say that the symmetry is "broken." The needed theoretical apparatus was worked out in the mid-1960s by physicists Peter Higgs, Robert Brout, François Englert and others. The inspiration came from a seemingly unrelated phenomenon: superconductivity, in which certain materials carry electric current with zero resistance at low temperatures. Although the laws of electromagnetism themselves are symmetrical, the behavior of electromagnetism within the superconducting material is not. A photon gains mass within a superconductor, thereby limiting the intrusion of magnetic fields into the material.

As it turns out, this phenomenon is a perfect prototype for the electroweak theory. If space is filled with a type of "superconductor" that affects the weak interaction rather than electromagnetism, it gives mass to the *W* and *Z* bosons and limits the range of the weak interactions. This superconductor consists of particles called Higgs bosons. The quarks and leptons also acquire their mass through their interactions with the Higgs boson [see "The Higgs Boson," by Martinus Veltman; Scientific American, November 1986]. By obtaining mass in this way, instead of possessing it intrinsically, these particles remain consistent with the symmetry requirements of the weak force.

The modern electroweak theory (with the Higgs) accounts very precisely for a broad range of experimental results. Indeed, the paradigm of quark and lepton constituents interacting by means of gauge bosons completely revised our conception of matter and pointed to the possibility that the strong, weak and electromagnet-

[WHY THE HIGGS?]

BREAKING SYMMETRY

A central question of the Standard Model is why the electroweak forces are asymmetrical: electromagnetism is long-ranged, whereas the weak nuclear force is short-ranged. Physicists think these forces are actually symmetrical, but their symmetry is hidden, or "broken."

MAGNETIC SPATIAL SYMMETRY

A simple analogy is an infinite grid of magnetic filings. The symmetry in this case is the equivalence of all directions in space.

The symmetry is evident at high temperatures. Heat jostles the filings every which way.

Symmetry

When the temperature drops, the filings lock one another in place. Although their alignment may seem more orderly, it is less symmetrical, because it singles out one randomly chosen direction over the others.

Broken symmetry

ELECTROWEAK SYMMETRY

This symmetry is more abstract. It means the freedom to decide which leptons are electrons and which are neutrinos or how to label up and down quarks.

In the symmetrical case, the lepton-naming convention (*represented by an arrow*) is set independently at each point in space. What one person calls an electron, another might call some mixture of electron and neutrino, and it would make no difference to their predictions.

In the broken symmetry, the convention is fixed everywhere. What one person calls an electron, all do. The Higgs field brings about this symmetry breaking.

Electroweak symmetry makes all the electroweak force particles massless.

Broken symmetry gives masses to the *W* and *Z* bosons, thereby restricting their range.

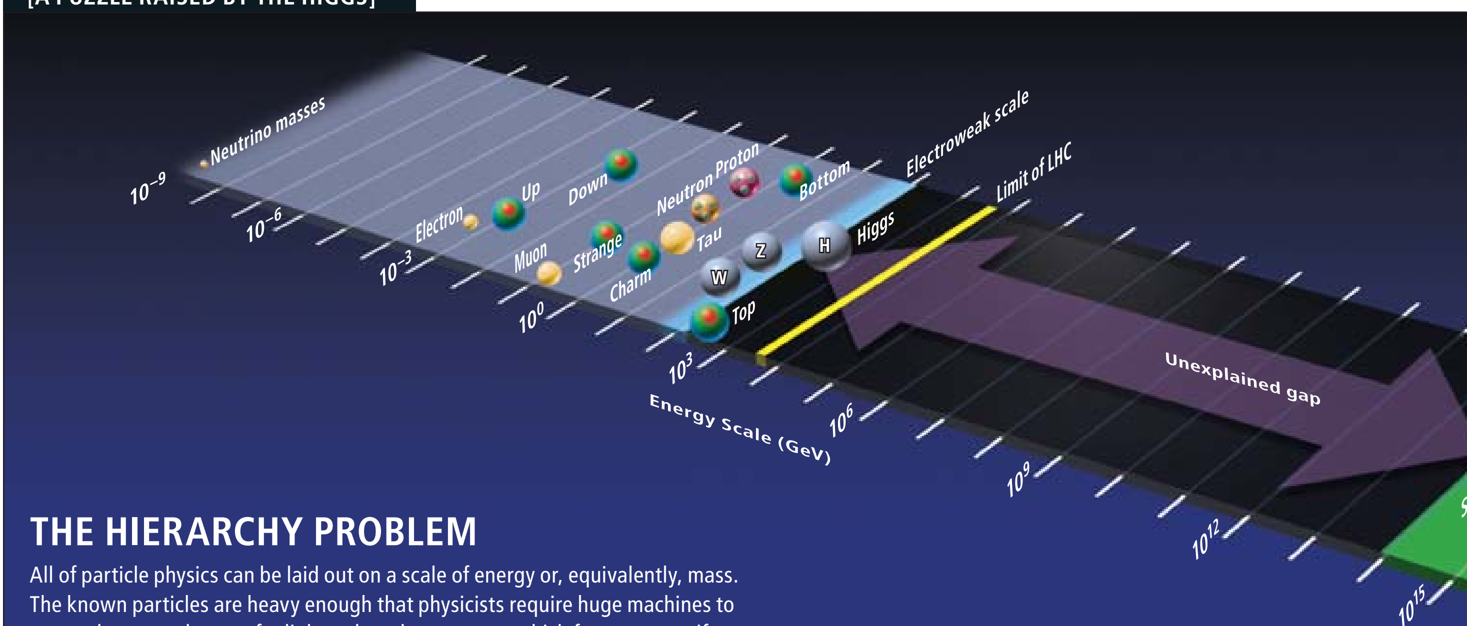
ic interactions meld into one when the particles are given very high energies. The electroweak theory is a stunning conceptual achievement, but it is still incomplete. It shows how the quarks and leptons might acquire masses but does not predict what those masses should be. The electroweak theory is similarly indefinite in regard to the mass of the Higgs boson itself: the existence of the particle is essential, but the theory does not predict its mass. Many of the outstanding problems of particle physics and cosmology are linked to the question of exactly how the electroweak symmetry is broken.

Where the Standard Model Tells Its Tale

Encouraged by a string of promising observations in the 1970s, theorists began to take the Standard Model seriously enough to begin to probe its limits. Toward the end of 1976 Benjamin W. Lee of Fermi National Accelerator Laboratory in Batavia, Ill., Harry B. Thacker, now at the University of Virginia, and I devised a thought experiment to investigate how the electroweak forces would behave at very high energies. We imagined collisions among pairs of *W*, *Z* and Higgs bosons. The exercise might seem slightly fanciful because, at the time of our work, not one of these particles had been observed. But physicists have an obligation to

SLIM FILMS

[A PUZZLE RAISED BY THE HIGGS]



THE HIERARCHY PROBLEM

All of particle physics can be laid out on a scale of energy or, equivalently, mass. The known particles are heavy enough that physicists require huge machines to create them, yet they are far lighter than the energy at which forces may unify or gravity may come into play. What enforces the separation? No one yet knows. This puzzle is especially acute for the Higgs. Extremely high-energy processes tend to pull its mass far above 1 TeV. What holds it down?

test any theory by considering its implications as if all its elements were real.

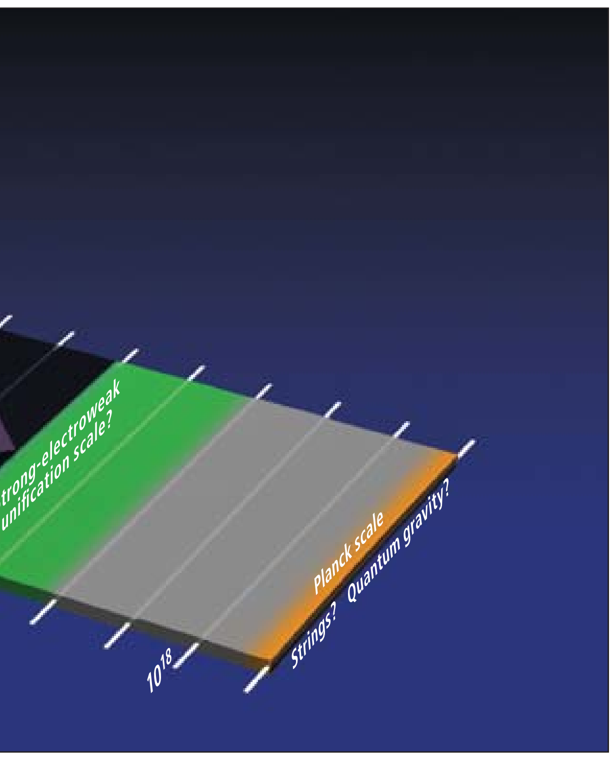
What we noticed was a subtle interplay among the forces generated by these particles. Extended to very high energies, our calculations made sense only if the mass of the Higgs boson were not too large—the equivalent of less than one trillion electron volts, or 1 TeV. If the Higgs is lighter than 1 TeV, weak interactions remain feeble and the theory works reliably at all energies. If the Higgs is heavier than 1 TeV, the weak interactions strengthen near that energy scale and all manner of exotic particle processes ensue. Finding a condition of this kind is interesting because the electroweak theory does not directly predict the Higgs mass. This mass threshold means, among other things, that something new—either a Higgs boson or other novel phenomena—is to be found when the LHC turns the thought experiment into a real one.

Experiments may already have observed the behind-the-scenes influence of the Higgs. This effect is another consequence of the uncertainty principle, which implies that particles such as the Higgs can exist for moments too fleeting to be observed directly but long enough to leave a subtle mark on particle processes. The Large Electron Positron collider at CERN, the previous inhabitant of the tunnel now used by the LHC, detected the work of such an unseen hand. Comparison of precise measurements with theory strongly hints that the Higgs exists and has a mass less than about 192 GeV.

For the Higgs to weigh less than 1 TeV, as required, poses an interesting riddle. In quantum theory, quantities such as mass are not set once and for all but are modified by quantum effects. Just as the Higgs can exert a behind-the-scenes influence on other particles, other particles can do the same to the Higgs. Those particles come in a range of energies, and their net effect depends on where precisely the Standard Model gives way to a deeper theory. If the model holds all the way to 10^{15} GeV, where the strong and electroweak interactions appear to unify, particles with truly titanic energies act on the Higgs and give it a comparably high mass. Why, then, does the Higgs appear to have a mass of no more than 1 TeV?

This tension is known as the hierarchy problem. One resolution would be a precarious balance of additions and subtractions of large numbers, standing for the contending contributions of different particles. Physicists have learned to be suspicious of immensely precise cancellations that are not mandated by deeper principles. Accordingly, in common with many of my colleagues, I think it highly likely that both the Higgs boson and other new phenomena will be found with the LHC.

SLIM FILMS



Supertechnifragilisticexpialidocious

Theorists have explored many ways in which new phenomena could resolve the hierarchy problem. A leading contender known as supersymmetry supposes that every particle has an as yet unseen superpartner that differs in spin [see "Is Nature Supersymmetric?" by H. E. Haber and G. L. Kane; Scientific American, June 1986]. If nature were exactly supersymmetric, the masses of particles and superpartners would be identical, and their influences on the Higgs would cancel each other out exactly. In that case, though, physicists would have seen the superpartners by now. We have not, so if supersymmetry exists, it must be a broken symmetry. The net influence on the Higgs could still be acceptably small if superpartner masses were less than about 1 TeV, which would put them within the LHC's reach.

Another option, called technicolor, supposes that the Higgs boson is not truly a fundamental particle but is built out of as yet unobserved constituents. (The term "technicolor" alludes to a generalization of the color charge that de-

[SOLVING THE HIGGS PUZZLE]

WANTED: NEW PHYSICS

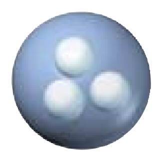
Whatever keeps the Higgs mass near the 1-TeV scale must come from beyond the Standard Model. Theorists have advanced many possible solutions. The Large Hadron Collider will decide. Here are three promising lines:

SUPERSYMMETRY

What tends to elevate the Higgs mass is its interaction with so-called virtual particles—copies of quarks, leptons and other particles that temporarily materialize around the Higgs. But if each particle species is paired with a superpartner, the two will offset each other, holding down the Higgs mass.

TECHNICOLOR

Perhaps the Higgs is not a truly elementary particle but a bundle of more fundamental constituents, much as the proton is a mini galaxy of quarks and gluons. Then the Higgs mass would derive mostly from the energy of its constituents and would not be so sensitive to high-energy processes that add to its mass.



EXTRA DIMENSIONS

If space has dimensions beyond the familiar three, particles might interact differently at high energies, and the conjectured unification energy might not be as high as physicists now think. The hierarchy problem would be recast or even eliminated.

[A HIGGS-LESS WORLD]

Hidden Symmetry That Shapes Our World

If there were no Higgs mechanism, what a different world it would be! Elementary particles of matter such as quarks and electrons would have no mass. Yet that does not mean the universe would contain no mass. An underappreciated insight from the Standard Model is that particles such as the proton and neutron represent matter of a novel kind. The mass of a proton, in contrast to macroscopic matter, is only a few percent of its constituent masses. (In fact, quarks account for not more than 2 percent of the proton's mass.) Most of the mass arises through the original form of Albert Einstein's famous equation, $m = E/c^2$, from the energy stored up in confining the quarks in a tiny volume. In identifying the energy of quark confinement as the origin of proton and neutron mass, we explain nearly all the visible mass of the universe, because luminous matter is made mostly of protons and neutrons in stars.

Quark masses do account for an important detail of the real world: that the neutron is slightly more massive than the proton. One might expect the proton to be the more massive one, because its electric charge contributes to its intrinsic energy—a source of self-energy the neutron lacks. But quark masses tip the balance the other way. In the no-Higgs zone, the proton would outweigh the neutron. Radioactive beta decay would be turned on its head. In our world, a neutron sprung from a nucleus decays into a proton, electron and antineutrino in about 15 minutes, on average. If quark masses were to vanish, a free proton would decay into a neutron, positron and neutrino. Consequently, hydrogen atoms could not exist. The lightest "nucleus" would be one neutron rather than one proton.

In the Standard Model, the Higgs mechanism differentiates electromagnetism from the weak force. In the absence of the Higgs, the strong force among quarks and gluons would induce the distinction. As the strong interaction confined the colored quarks into colorless objects like the proton, it would also act to distinguish the weak and electromagnetic interactions, giving small masses to the *W* and *Z* bosons while leaving the photon massless. This manifestation of the strong force would not give any appreciable mass to the electron or the quarks. If it, rather than the Higgs, operated, beta decay would operate millions of times faster than in our world.

Some light nuclei would be produced in the early no-Higgs universe and survive, but they would not form atoms we would recognize. An atom's radius is inversely proportional to the electron's mass, so if the electron has zero mass, atoms—less than a nanometer across in our world—would be infinitely big. Even if other effects gave electrons a tiny mass, atoms would be macroscopic. A world without compact atoms would be a world without chemistry and without stable composite structures like our solids and liquids. *—C.Q.*

WITHOUT THE HIGGS, atoms could be several inches across or bigger.

A DECADE OF DISCOVERY

Many people think of the past decade in particle physics as an era of consolidation, but in fact it has been a vibrant time, setting the stage for revolutions to come.

A NEW LAW OF NATURE
Experiments have tested the electroweak theory, a key element of the Standard Model, over a staggering range of distances, from the subnuclear to the galactic.

NEUTRINO MASS
Particle detectors have established that neutrinos can morph from one type to another. These elusive particles must have mass, which the Standard Model does not naturally explain.

TOP QUARK
Fermilab experiments discovered the top quark in collisions of protons and their antimatter counterpart, antiprotons. The top stands out because its mass is some 40 times that of its partner, the bottom quark.

AN IMPERFECT MIRROR
KEK (the Japanese high-energy physics laboratory) and the Stanford Linear Accelerator Center detected differences between the decays of B mesons and of their antiparticles. Such subtle asymmetries bear on why the universe contains so little antimatter.

NOVEL FORMS OF MATTER AND ENERGY
A remarkable concordance of astronomical observations indicates that we live in an approximately flat universe dominated by dark matter and an unidentified form of dark energy that drives cosmic acceleration.

fines the strong force.) If so, the Higgs is not fundamental. Collisions at energies around 1 TeV (the energy associated with the force that binds together the Higgs) would allow us to look within it and thus reveal its composite nature. Like supersymmetry, technicolor implies that the LHC will set free a veritable menagerie of exotic particles.

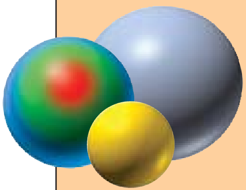
A third, highly provocative idea is that the hierarchy problem will go away on closer examination, because space has additional dimensions beyond the three that we move around in. Extra dimensions might modify how the forces vary in strength with energy and eventually meld together. Then the melding—and the onset of new physics—might not happen at 10^{12} TeV but at a much lower energy related to the size of the extra dimensions, perhaps only a few TeV. If so, the LHC could offer a peek into those extra dimensions [see "The Universe's Unseen Dimensions," by Nima Arkani-Hamed, Savas Dimopoulos and Georgi Dvali; Scientific American, August 2000].

One more piece of evidence points to new phenomena on the TeV scale. The dark matter that makes up the bulk of the material content

PAT LACROIX *Getty Images*

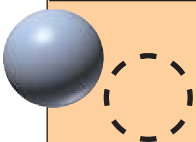
[WHAT TO EXPECT]

FIVE GOALS FOR THE LHC



REDISCOVER THE STANDARD MODEL
The first goal of the collider is not to probe the new but to confirm the old. The machine will produce familiar particles in prodigious numbers (several top quarks per second, for example) and scrutinize them with increasing refinement. Not only does this test the machine and its instruments, it sets precise benchmarks for determining whether new phenomena are indeed new.

DETERMINE WHAT BREAKS THE ELECTROWEAK SYMMETRY
The collider will seek the Higgs boson (or what stands in its place) and determine its properties. Does the Higgs provide mass not only to the *W* and *Z* particles but also to the quarks and leptons?

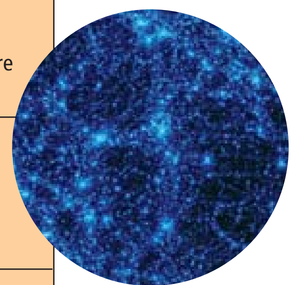


SEARCH FOR NEW FORCES OF NATURE
New force particles would decay into known particles such as electrons and their antimatter counterparts, positrons. Such forces would indicate new symmetries of nature and might guide physicists toward a unified understanding of all the interactions.

PRODUCE DARK MATTER CANDIDATES
By observing neutral, stable particles created in high-energy collisions, the collider could help solve one of astronomy's greatest puzzles and test researchers' understanding of the history of the universe.

ABOVE ALL, EXPLORE!
The collider will examine its immense new domain for evidence of hidden spacetime dimensions, new strong interactions, supersymmetry and the totally unexpected. Physicists will have to be attentive to connections among today's great questions and alert to new questions the collider will open up.

Dark matter simulation



of the universe appears to be a novel type of particle [see "The Search for Dark Matter," by David B. Cline; SCIENTIFIC AMERICAN, March 2003]. If this particle interacts with the strength of the weak force, then the big bang would have produced it in the requisite numbers as long as its mass lies between approximately 100 GeV and 1 TeV. Whatever resolves the hierarchy problem will probably suggest a candidate for the dark matter particle.

Revolutions on the Horizon

Opening the TeV scale to exploration means entering a new world of experimental physics. Making a thorough exploration of this world—where we will come to terms with electroweak symmetry breaking, the hierarchy problem and dark matter—is the top priority for accelerator experiments. The goals are well motivated and matched by our experimental tools, with the LHC succeeding the current workhorse, Fermilab's Tevatron collider. The answers will not only be satisfying for particle physics, they will deepen our understanding of the everyday world.

But these expectations, high as they are, are still not the end of the story. The LHC could well find clues to the full unification of forces or indications that the particle masses follow a rational pattern [see "A Unified Physics by 2050?" by Steven Weinberg; SCIENTIFIC AMERICAN, December 1999]. Any proposed interpretation of new particles will have consequences for rare decays of the particles we already know. It is very likely that lifting the electroweak veil will bring these problems into clearer relief, change the way we think about them and inspire future experimental thrusts.

Cecil Powell won the 1950 Nobel Prize in Physics for discovering particles called pions—proposed in 1935 by physicist Hideki Yukawa to account for nuclear forces—by exposing highly sensitive photographic emulsions to cosmic rays on a high mountain. He later reminisced: "When [the emulsions] were recovered and developed in Bristol, it was immediately apparent that a whole new world had been revealed.... It was as if, suddenly, we had broken into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened in great profusion." That is just how I imagine our first look at the TeV scale. ■

SLIM FILMS (*illustration*); ANDREY KRAVTSOV (*dark matter*)

MORE TO EXPLORE

LHC Physics: The First One–Two Year(s). F. Gianotti and M. Mangano in *Proceedings of the 2nd Italian Workshop on the Physics of Atlas and CMS,* pages 3–26. Edited by G. Carlino and P. Paolucci. Frascati Physics Series, Vol. 38; 2005. Preprint available at **www.arxiv.org/abs/hep-ph/0504221**

Particles and the Standard Model. Chris Quigg in *The New Physics for the Twenty-First Century.* Edited by Gordon Fraser. Cambridge University Press, 2006.

Chris Quigg's Web site (with links to slides and video of his public talks): **http://lutece.fnal.gov**

The LHC Project: **http://lhc.web.cern.ch/lhc**

ATLAS Experiment at the LHC: **www.atlasexperiment.org**

Compact Muon Solenoid Experiment at the LHC: **http://cms.cern.ch**

Collider Detector at Fermilab: **www-cdf.fnal.gov**

DØ Experiment: **www-d0.fnal.gov**

BUILDING THE NEXT-GENERATION COLLIDER

To further investigate the intricacies of high-energy particle physics, researchers must construct a more powerful electron-positron collider

By Barry Barish, Nicholas Walker and Hitoshi Yamamoto

KEY CONCEPTS

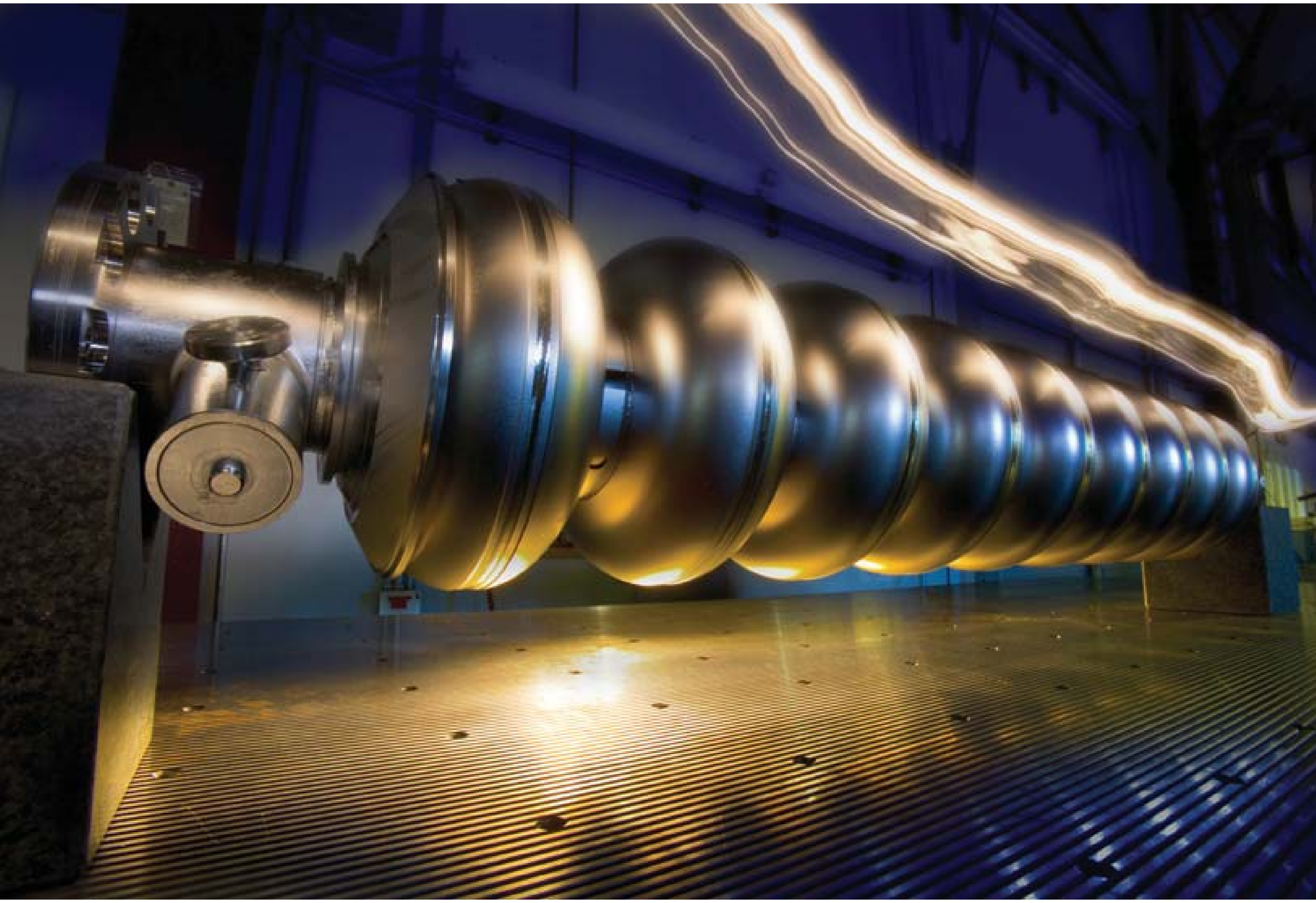
- The logical successor to the Large Hadron Collider (LHC) is the International Linear Collider (ILC), a proposed facility that would smash electrons and positrons together.
- The ILC's design calls for two 11.3-kilometer-long linear accelerators that would use strong electric fields to accelerate particles through a string of vacuum chambers called cavities.
- In addition to overcoming technical challenges, the ILC's planners must secure funding for the project and choose a site before the collider can be built.

—The Editors

A new era in physics will open up when the Large Hadron Collider (LHC) extends the reach of subatomic particle investigations to unprecedented energy scales. But even before researchers initiate the first high-energy collisions in the LHC's giant storage ring, located under the French-Swiss border, they are already contemplating and working toward the next great particle accelerator. And the consensus choice of the particle physics community is a proposed facility called the International Linear Collider (ILC), a machine more than 30 kilometers long that would smash electrons and positrons together at velocities very close to the speed of light. (The positron is the antimatter counterpart of the electron, identical in mass but opposite in charge.)

Far more powerful than previous electron-positron colliders, the ILC would enable physicists to follow up any groundbreaking discoveries made by the LHC. The LHC is designed to investigate the collisions of protons, each of which is actually a bundle of three quarks bound together by gluons (the particles carrying the strong nuclear force). Because the quarks and gluons within a proton are constantly interacting, a proton-proton collision is an inherently messy affair. Researchers cannot be certain of the energy of each quark at the moment of the collision, and this uncertainty makes it difficult to determine the properties of novel particles produced by the impact. But the electron and positron are fundamental particles rather than composites, so physicists working with an electron-positron collider can know the energy of each collision to great accuracy. This capability would make the ILC an extremely useful tool for precisely measuring the masses and other characteristics of newly discovered particles [*see box on page 58*].

More than 1,600 scientists and engineers from nearly 300 laboratories and universities around the world are now working on the design of the ILC and the development of the detectors that would analyze its particle collisions. In February 2007 our design team released a cost estimate for the machine: $6.7 billion (not including the expense of the detectors). We have done studies comparing the costs of locating the ILC at three possible sites—CERN, the European laboratory for particle physics near Geneva, the Fermi National Accelerator Laboratory in Batavia, Ill., and the mountains of Japan—and we are developing schemes for the governance of a truly international laboratory. Although the ILC's price tag may seem steep, it is roughly comparable to the costs of large science programs such as the LHC and the ITER nuclear fusion reactor. And if everything proceeds as hoped, the ILC could start illuminating the frontiers of particle physics sometime in the 2020s.



Birth of a Collider

In August 2005 about 600 physicists from around the world gathered in Snowmass, Colo., to start planning the development of the ILC. But the true beginnings of the project go back to the commissioning of CERN's Large Electron-Positron (LEP) collider in 1989. The LEP accelerated electrons and positrons in a storage ring with a circumference of 27 kilometers, then smashed the particles together, producing impacts with energies as high as 180 billion electron volts (GeV). It was clear, though, that the LEP would be the largest collider of its kind, because accelerating electrons and positrons to energies in the trillion-electron-volt (TeV) scale—also known as the terascale—would require a ring several hundred kilometers in circumference and would be completely cost-prohibitive.

The major obstacle to a storage ring solution is synchrotron radiation: relatively light particles such as electrons and positrons happily radiate their energy as they speed around the ring, their paths continuously bent by the ring's many dipole magnets. Because these losses make it progressively harder to accelerate the particles, the cost of building such a collider is proportional to the square of the collision energy: a machine that doubled the LEP energies would cost four times as much. (The energy losses are not as severe for colliders that accelerate heavier particles such as protons; hence, the tunnel dug for the LEP ring is now being used by the LHC.)

A more cost-effective solution is a linear collider, which avoids synchrotron radiation by accelerating particles in straight lines rather than in a ring. In the ILC design, two 11.3-kilometer-long linear accelerators, or linacs—one for electrons, one for positrons—are aimed at each other, with the collision point in the middle. The

BASIC ELEMENT of the International Linear Collider design is a one-meter-long niobium cavity consisting of nine bead-shaped cells. When cooled to very low temperatures, the cavity becomes superconducting and can efficiently generate the electric fields needed to accelerate the electrons and positrons.

FERMILAB VISUAL MEDIA SERVICES

downside is that the electrons and positrons must be accelerated from rest up to the collision energy on each pulse of the machine instead of building up speed with each circuit of the storage ring. To obtain higher collision energies, one can simply build longer linear accelerators. The cost of the facility is directly proportional to the collision energy, giving linear colliders a clear advantage over the storage ring concept at the TeV scale.

At the same time that the LEP was being constructed in Europe, the U.S. Department of Energy was building a competing machine at the Stanford Linear Accelerator Center (SLAC). SLAC's device, which was considered a proof of principle of the linear collider concept, used a three-kilometer-long linac to accelerate bunches of electrons and positrons in tandem, boosting them to energies of about 50 GeV. The bunches were then magnetically separated and bent around to bring them into a head-on collision. Although SLAC's machine—which operated from 1989 to 1998—was not exactly a true linear collider, because it employed only one linac, the facility paved the way for the ILC.

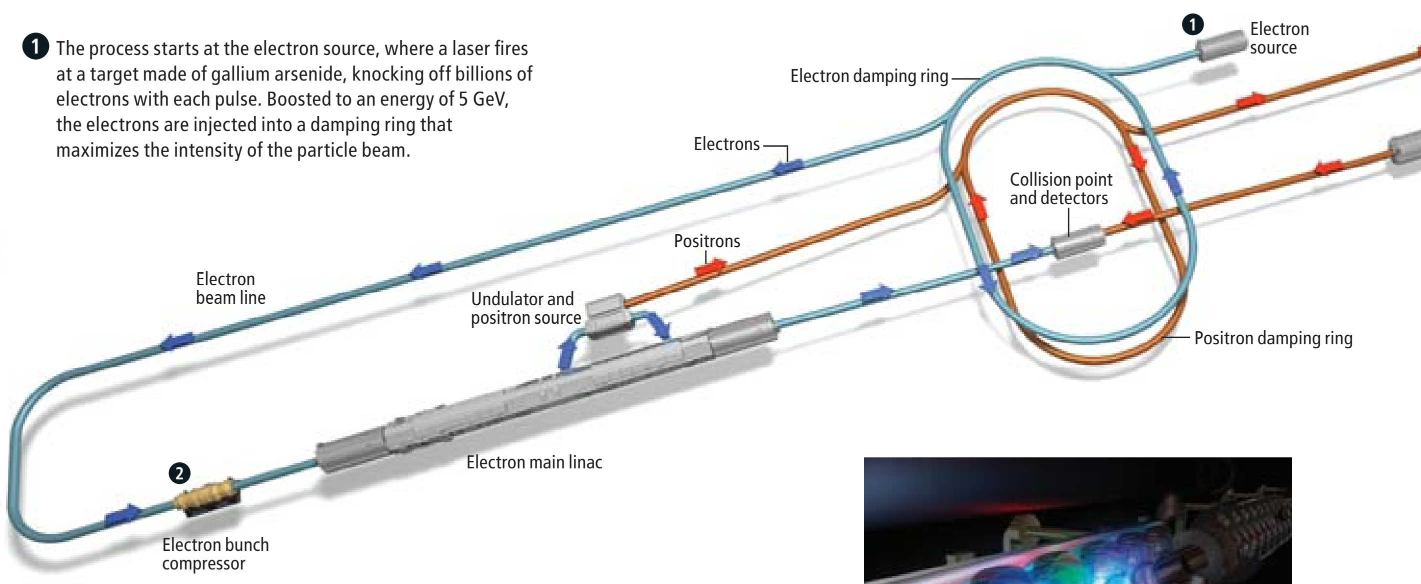
Planning for a TeV-scale linear collider began in earnest in the late 1980s and early 1990s when several competing technologies were proposed. As researchers developed these proposals over the next decade, they focused on the need to keep the linear collider affordable. Finally, in August 2004, a panel of 12 independent experts assessed the proposed technologies and recommended a design conceived by the TESLA group, a collaboration of scientists from more than 40 institutions, coordinated by the

[HOW IT WOULD WORK]

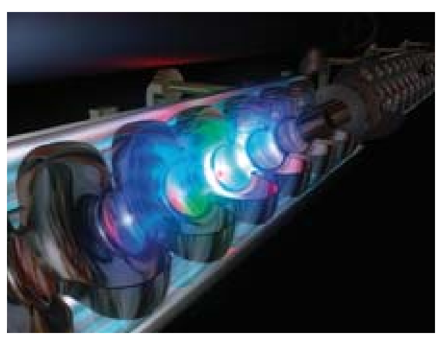
COLLIDER OF THE FUTURE

More than 30 kilometers long, the proposed ILC would be the most powerful linear collider ever built. Its linear accelerators, or linacs, would boost electrons (*blue*) and positrons (*orange*) to energies of 250 billion electron volts (GeV), then smash the particle beams into one another.

1 The process starts at the electron source, where a laser fires at a target made of gallium arsenide, knocking off billions of electrons with each pulse. Boosted to an energy of 5 GeV, the electrons are injected into a damping ring that maximizes the intensity of the particle beam.



2 The electrons are transferred to a bunch compressor that squeezes the clusters of particles and accelerates them to 15 GeV. Then the electrons proceed to one of the main linacs, which speeds the particles to 250 GeV. Midway through the linac, the electron bunches take a detour to a special magnet called an undulator, which radiates some of their energy into gamma rays. The gamma photons then strike a rotating target to produce electron-positron pairs; the positrons are captured, accelerated to an energy of 5 GeV and then shunted to another damping ring.

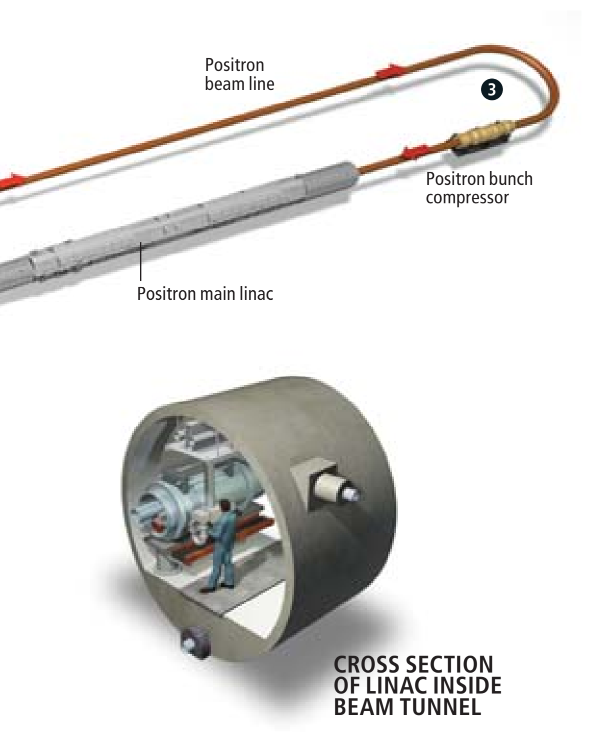


Computer simulation of the electric field inside the linac that accelerates the particles.

DESY research center in Hamburg, Germany. Under this proposal, the electrons and positrons would travel through a long series of vacuum chambers called cavities. Constructed from the metal niobium, these cavities can be superconducting—when cooled to very low temperatures, they can conduct electricity without resistance. This phenomenon would enable the efficient generation of a strong electric field inside the cavities that would oscillate at radio frequencies, about one billion times per second. This oscillating field would accelerate the particles toward the collision point.

The basic element of this superconducting radio-frequency (SCRF) design is a one-meter-long niobium cavity consisting of nine cells that can be cooled to a temperature of two kelvins (–456 degrees Fahrenheit). Eight or nine cavities would be attached end to end in a string and immersed in ultracold liquid helium in a tank called a cryomodule [*see illustration on page 59*]. Each of the two main linacs in the ILC would require about 900 cryomodules, giving the collider about 16,000 cavities in all. Researchers at DESY have so far constructed 10 prototype cryomodules, five of which are currently installed in FLASH, a laser at DESY that employs high-energy electrons. The SCRF technology will also be incorporated into DESY's upcoming European X-Ray Free-Electron Laser (XFEL), which will string together 101 cryomodules to form a superconducting linac that can accelerate electrons to about 17.5 GeV.

Because the ILC's linacs can be shorter (and hence less expensive) if the cavities can generate a stronger electric field, the design team has set an aggressive goal of improving the performance of the SCRF system until it can give the particles an energy boost of 35 million electron volts (MeV) for every meter they travel. Several prototype cavities have already exceeded this goal, but it remains a challenge to mass-produce such devices. The key to high performance is ensuring that the inner surface of the cavity is ultraclean and defect-free. The preparation of the cavities and their installation in the cryomodules must be done in clean-room environments.



3 The positrons travel to the opposite end of the ILC, where they are compressed and accelerated to 250 GeV by the other main linac. Magnetic lenses focus the electron and positron beams as they race toward one another, and detectors at the collision point analyze the particles hurtling from the high-energy impacts.

DON FOLEY (*collider schematic*); DESY HAMBURG (*field simulation*)

The ILC in a Nutshell

The ILC design team has already established the basic parameters for the collider [*see box at left*]. The machine will be about 31 kilometers long, with most of that length taken up by the two superconducting linacs that will set up electron-positron collisions with 500 GeV energies. (A 250-GeV electron striking a 250-GeV positron moving in the opposite direction will result in a collision with a center-of-mass energy of 500 GeV.) At a rate of five times per second, the ILC will generate, accelerate and collide nearly 3,000 electron and positron bunches in a one-millisecond-long pulse, corresponding to an average total power of about 10 megawatts for each beam. The overall efficiency of the machine—that is, the fraction of electrical power converted to beam power—will be about 20 percent, so the two linacs will require a total of about 100 megawatts of electricity to accelerate the particles.

To produce the electron beam, a laser will fire at a target made of gallium arsenide, knocking off billions of electrons with each pulse. These particles will be spin-polarized—all their

[THE AUTHORS]

Barry Barish, Nicholas Walker and Hitoshi Yamamoto are all well versed in the science of electron-positron collisions. Barish is director of the global design effort for the International Linear Collider (ILC), as well as Linde Professor of Physics Emeritus at the California Institute of Technology. His research interests range from neutrinos to magnetic monopoles to gravitational waves. Walker, an accelerator physicist based at DESY in Hamburg, Germany, has worked 15 years on linear collider design and is one of three project managers for the ILC Engineering Design Phase. Yamamoto, a professor of physics at Tohoku University in Japan, has worked on collider experiments conducted at the Stanford Linear Accelerator Center, the Cornell Electron Storage Ring and Japan's High Energy Accelerator Research Organization (KEK).

SAMPLE SITES

The ILC's planners have analyzed the costs of locating the collider at three possible sites:

EUROPE
At CERN, the European laboratory for particle physics near Geneva.

U.S.
At the Fermi National Accelerator Laboratory in Batavia, Ill.

JAPAN
Along a mountain range in an unspecified part of the country.

spin axes will point in the same direction—which is important for many particle physics investigations. The electrons will be rapidly accelerated in a short SCRF linac to an energy of 5 GeV, then injected into a 6.7-kilometer storage ring at the center of the complex. As the electrons circulate and emit synchrotron radiation, the bunches of particles will be damped—that is, their volume will decrease, and their charge density will increase, maximizing the intensity of the beam.

When the electron bunches exit the damping ring 200 milliseconds later, each will be about nine millimeters long and thinner than a human hair. The ILC will then compress each electron bunch to a length of 0.3 millimeter to optimize its acceleration and the dynamics of its subsequent collisions with the corresponding positron bunch inside the detector. During the compression, the bunches will be boosted to an energy of 15 GeV, after which they will be injected into one of the main 11.3-kilometer-long SCRF linacs and accelerated to 250 GeV.

Midway through the linac, when the particles are at an energy of 150 GeV, the electron bunches will take a small detour to produce the positron bunches. The electrons will be deflected into a special magnet known as an undulator, where they will radiate some of their energy into gamma rays. The gamma photons will be focused onto a thin titanium alloy target that rotates about 1,000 times per minute, and the impacts will produce copious numbers of electron-positron pairs. The positrons will be captured, accelerated to an energy of 5 GeV, transferred to another damping ring and finally sent to the other main SCRF linac at the opposite end of the ILC. Once the electrons and positrons are fully accelerated to 250 GeV and rapidly converging toward the collision point, a series of magnetic lenses will focus the high-energy bunches to flat ribbon beams about 640 nanometers (billionths of a meter) wide and six nanometers high. After the collisions, the bunches will be extracted from the interaction region and removed to a so-called beam dump, a target that can safely absorb the particles and dissipate their energy.

Every subsystem of the ILC will push the technological envelope and present major engineering challenges. The

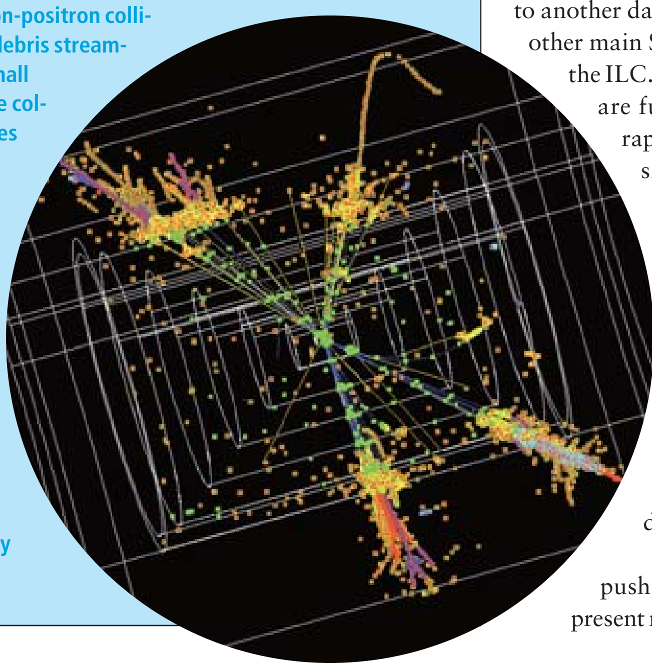
[A COLLIDER COMPARISON]

The Hammer and the Scalpel

To understand the complementary relation between the Large Hadron Collider (LHC) and the proposed International Linear Collider (ILC), imagine the former as a hammer that breaks open a walnut and the latter as a scalpel that carefully slices the bits of meat inside. The LHC will accelerate protons to energies of seven trillion electron volts (TeV), giving each head-on proton-proton collision a total energy of 14 TeV and providing researchers with their first direct look at physics at this energy scale. The collisions may generate the production of particles whose existence has been hypothesized but not yet observed. One such particle is the Higgs boson. (According to the Standard Model—the widely accepted theory of particle physics that can explain electromagnetism and the weak and strong nuclear forces—the Higgs endows all other particles with mass.) Other examples are the supersymmetric particles, which are hypothesized partners of the known particles. (The putative partner of the electron, for example, is called the selectron; the photon's partner is the photino.) Furthermore, the LHC may find evidence for extra dimensions that can be detected only by observing high-energy events.

If the Higgs boson does exist, physicists expect that the LHC will detect the particle, measure its mass and determine its interactions with other particles. But scientists will not be able to specify the detailed properties of the Higgs from the LHC's messy proton-proton collisions. The more precise ILC would be needed to measure important characteristics such as the strength of the Higgs's interactions. This information would be invaluable to physicists because it could test the validity of the Standard Model: Does it correctly describe high-energy events, or are other theories needed? Investigations of supersymmetric particles in the ILC could also help physicists flesh out the details of new theories. The results may reveal whether some of these particles could be constituents of the so-called dark matter that makes up one quarter of the energy content of the universe.

Yet another particle that could be revealed by the LHC is the hypothesized *Z*-prime boson, a counterpart to the *Z* boson, which is one of the carriers of the weak nuclear force. Because the discovery of the *Z*-prime particle would indicate the existence of a new fundamental force of nature, physicists would be very interested in determining the properties of this force, its origins, its relation to the other forces in a unified framework and its role in the earliest moments of the big bang. The ILC would play a definitive role in addressing such issues. Finally, if history is any guide, it seems very likely that the LHC and the ILC will discover unanticipated new phenomena that are at least as interesting and important as the ones already discussed. *—B.B., N.W. and H.Y.*



COMPUTER SIMULATION of an electron-positron collision in the ILC shows the particle debris streaming from the impact point. Each small square indicates a hit on one of the collider's detectors; a group of squares with the same color represents a particle shower. From these data, researchers deduce the nature of the debris: the yellow lines are the paths of neutral particles (mostly photons), and the blue lines are the trajectories of charged particles (primarily pions, consisting of pairs of quarks). This simulation predicts what researchers would see if the electron-positron collision produced a Higgs boson and a *Z* boson, both of which would rapidly decay to lighter particles.

NORMAN GRAF

CRYOMODULES will bathe the ILC's string of niobium cavities with liquid helium to make them cold enough to become superconducting. The devices shown here were tested at the DESY research center in Hamburg, Germany.

collider's damping rings must achieve beam qualities several times better than those of existing electron storage rings. What is more, the high beam quality must be preserved throughout the compression, acceleration and focusing stages. The collider will require sophisticated diagnostics, state-of-the-art beam-tuning procedures and a very precise alignment of its components. Building the positron production system and aiming the nanometer-size beams at the collision point will be demanding tasks.

Developing detectors that can analyze the collisions in the ILC will also be challenging. To determine the strengths of the interactions between the Higgs boson and other particles, for example, the detectors will need to measure the momentum and creation points of charged particles with resolutions that are an order of magnitude better than those of previous devices. Scientists are now working on new tracking and calorimeter systems that will allow researchers to harvest the rich physics of the ILC.

The Next Steps

Although the ILC team has chosen a design for the collider, much more planning needs to be done. Over the next few years, while the LHC starts collecting and analyzing data from its proton-proton collisions, we will strive to optimize the ILC design to ensure that the electron-positron collider achieves the best possible performance at a reasonable cost. We do not yet know where the ILC will be located; that decision will most likely hinge on the amount of financial support that governments are willing to invest in the project. In the meantime, we will continue to analyze the sample ILC sites in Europe, the U.S. and Japan. Differences in geology, topography, and local standards and regulations may lead to different construction approaches and cost estimates. Ultimately, many details of the ILC design will depend on exactly where the collider is built.

In any event, our planning will allow us to move forward at full speed as soon as the scientific discoveries at the LHC reveal the best targets for follow-up research. In parallel with the technical design work, we are creating models for dividing the governance of the ILC project so that each constituency of physicists will have a say. This ambitious undertaking has been truly global in its conception, development and design, and we expect it to be thoroughly international in its construction and operation as well. ■

Every subsystem of the International Linear Collider will push the technological envelope and present major engineering challenges.

DESY HAMBURG (*cryomodule*); DESY (*superconducting TESLA cavity*)

➥ MORE TO EXPLORE

More information about the design, technology and physics of the International Linear Collider can be found at:

www.linearcollider.org

www.linearcollider.org/gateway

www.linearcollider.org/cms/?pid=1000437

www.fnal.gov/directorate/icfa/ITRP_Report_Final.pdf

http://physics.uoregon.edu/%7Elc/wwstudy/lc_consensus.html

▶ GIANT FLOATING ICE SHELF off the Antarctic Peninsula marks the end of a great flow of ice. The flow begins with snowfall in the continental interior, which compacts into ice and slowly makes its way to the edge of the continent and into the ocean. As climate change accelerates the breakup of ice shelves, it can speed the movement of the "upstream" ice across the land and into the sea.

The Unquiet Ice

KEY CONCEPTS

- The land-based ice sheets of Greenland and Antarctica hold enough water to raise global sea level by more than 200 feet.
- A complex "plumbing system" of rivers, lakes and meltwater lies under the ice sheets. That water "greases" the flow of vast streams of ice toward the ocean.
- For millennia, the outgoing discharge of ice has been balanced by incoming snowfall. But when warming air or surface meltwater further greases the flow or removes its natural impediments, huge quantities of ice lurch seaward.
- Models of potential sea-level rise from climate change have ignored the effects of subglacial water and the vast streams of ice on the flow of ice entering the sea.

—The Editors

Abundant liquid water newly discovered underneath the world's great ice sheets could intensify the destabilizing effects of global warming on the sheets. Then, even without melting, the sheets may slide into the sea and raise sea level catastrophically

By Robin E. Bell

As our P-3 flying research laboratory skimmed above the icy surface of the Weddell Sea, I was glued to the floor. Lying flat on my stomach, I peered through the hatch on the bottom of the plane as seals, penguins and icebergs zoomed in and out of view. From 500 feet up everything appeared in miniature except the giant ice shelves—seemingly endless expanses of ice, as thick as the length of several football fields, that float in the Southern Ocean, fringing the ice sheets that virtually cover the Antarctic landmass. In the mid-1980s all our flights were survey flights: we had 12 hours in the air once we left our base in southern Chile, so we had plenty of time to chat with the pilots about making a forced landing on the ice shelves. It was no idle chatter. More than once we had lost one of our four engines, and in 1987 a giant crack became persistently visible along the edge of the Larsen B ice shelf, off the Antarctic Peninsula—making it abundantly clear that an emergency landing would be no gentle touchdown.

The crack also made us wonder: Could the ocean underlying these massive pieces of ice be warming enough to make them break up, even though they had been stable for more than 10,000 years?

Almost a decade later my colleague Ted Scambos of the National Snow and Ice Data Center in Boulder, Colo., began to notice a change in weather-satellite images of the same ice shelves that I had seen from the P-3. Dark spots, like freckles, began to appear on the monotonously white ice. Subsequent color images showed the dark spots to be areas of brilliant dark blue. Global climate change was warming the Antarctic Peninsula more rapidly than any other place on earth, and parts of the Larsen B ice surface were becoming blue ponds of meltwater. The late glaciologist Gordon de Q. Robin and Johannes Weertman, a glaciologist at

Northwestern University, had suggested several decades earlier that surface water could crack open an ice shelf. Scambos realized that the ponding water might do just that, chiseling its way through the ice shelf to the ocean waters below it, making the entire shelf break up. Still, nothing happened.

Nothing, that is, until early in the Antarctic summer of 2001–2002. In November 2001 Scambos got a message he remembers vividly from Pedro Skvarca, a glaciologist based at the Argentine Antarctic Institute in Buenos Aires who was trying to conduct fieldwork on Larsen B. Water was everywhere. Deep cracks were forming. Skvarca was finding it impossible to work, impossible to move. Then, in late February 2002, the ponds began disappearing, draining—the water was indeed chiseling its way through the ice shelf. By mid-March remarkable satellite images showed that some 1,300 square miles of Larsen B, a slab bigger than the state of Rhode Island, had fragmented. Nothing remained of it except an armada of ice chunks, ranging from the size of Manhattan to the size of a microwave oven. Our emergency landing site, stable for thousands of years, was gone. On March 20 Scambos's striking satellite images of the collapsing ice shelf appeared above the fold on the front page of the *New York Times* [*see sidebar at bottom of page 63*].

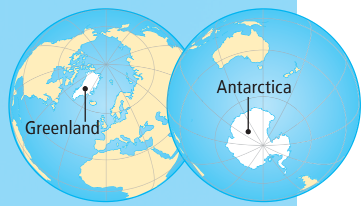
Suddenly the possibility that global warming might cause rapid change in the icy polar world was real. The following August, as if to underscore that possibility, the extent of sea ice on the other side of the globe reached a historic low, and summer melt on the surface of the Greenland ice sheet exceeded anything previously observed. The Greenland meltwaters, too, gushed into cracks and open holes in the ice known as moulins—and then, presumably, plunged to the base of the ice sheet, carrying the summer heat with them. There, instead of mix-

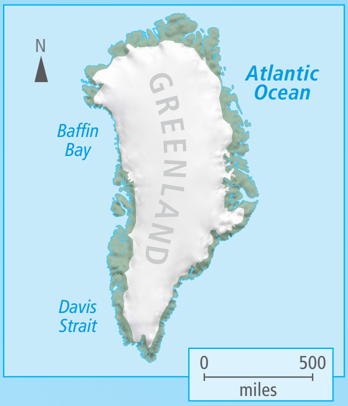
▲ JUST ADD ICE: **No melting needed. Water level in the glass at the left rises when ice is added (*center*). When the ice melts, the water level remains unchanged (*right*). Global sea level rises the same way when ice slides off land and into the ocean.**

SEBASTIAN COPELAND www.antarcticabook.com (*ice shelf*); BRIAN MARANAN PINEDA (*glasses*)

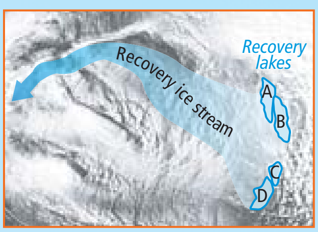
[THE THREAT]

World's Greatest Ice Sheets





Three ice sheets, one covering most of Greenland and two covering Antarctica (separated by the Transantarctic Mountains), hold 99 percent of the ice that would raise sea levels if global warming caused it to melt or go afloat (the other 1 percent is locked up in mountain glaciers). The Greenland ice sheet lies almost entirely on bedrock and flows into the ocean roughly half as meltwater and half as glacial ice. In Antarctica most of the ice flows into the ocean from regions of relatively fast-moving solid ice called ice streams that drain the ice from slower-moving regions.



◀ Under the ice in Antarctica investigators have discovered an extensive network of lakes and rivers; the map above shows the "subglacial" positions of several such features. The Recovery lakes (*inset at left*), four subglacial lakes discovered by the author and designated A, B, C and D, are the first lakes known to contribute to the start-up of a fast-moving stream of ice. The Recovery ice stream flows some 500 miles to the Filchner ice shelf.

➡ ON THE WEB

Antarctica has never looked so good as it does in a new digital map that combines 1,100 satellite images into a seamless mosaic of the entire continent. Check out http://lima.usgs.gov

ing with seawater, as it did in the breakup of Larsen B, the water probably mixed with mud, forming a slurry that was smoothing the way across the bedrock—"greasing," or lubricating, the boundary between ice and rock. But by whatever mechanism, the giant Greenland ice sheet was accelerating across its rocky moorings and toward the sea.

More recently, as a part of the investigations of the ongoing International Polar Year (IPY) [*see sidebar on page 66*], my colleagues and I have been tracing the outlines of a watery "plumbing" system at the base of the great Antarctic ice sheets as well. Although much of the liquid water greasing the skids of the Antarctic sheets probably does not arrive from the surface, it has the same lubricating effect. And there, too, some of the ice sheets are responding with accelerated slippage and breakup.

Why are those processes so troubling and so vital to understand? A third of the world's population lives within about 300 feet above sea level, and most of the planet's largest cities are situated near the ocean. For every 150 cubic miles of ice that are transferred from land to the sea, the global sea level rises by about a 16th of an inch. That may not sound like a lot, but consider the volume of ice now locked up in the planet's three greatest ice sheets. If the West Antarctic ice sheet were to disappear, sea level would rise almost 19 feet; the ice in the Greenland ice sheet could add 24 feet to that; and the East Antarctic ice sheet could add yet another 170 feet to the level of the world's oceans: more than 213 feet in all [*see box at top of opposite page*]. (For comparison, the Statue of Liberty, from the top of the base to the top of the torch, is about 150 feet tall.) Liquid water plays a crucial and, until quite recently, underappreciated role in the internal movements and seaward flow of ice sheets. Determining how liquid water forms, where it occurs and how climate change can intensify its effects on the world's polar ice are paramount in predicting—and preparing for—the consequences of global warming on sea level.

Rumblings in the Ice

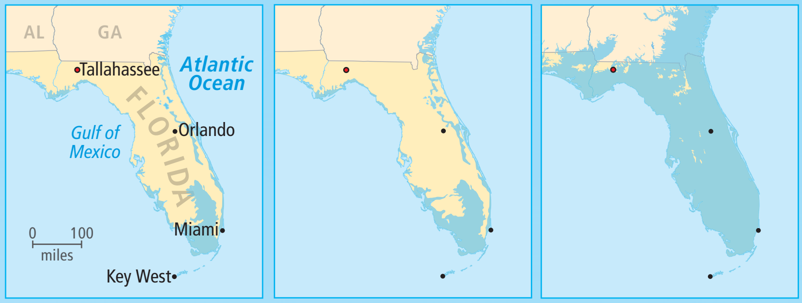
Glaciologists have long been aware that ice sheets do change; investigators simply assumed that such changes were gradual, the kind you infer from carbon 14 dating—not the kind, such as the breakup of the Larsen B ice shelf, that you can mark on an ordinary calendar. In the idealized view, an ice sheet accumulates snow—originating primarily in evaporated seawater—at its center and sheds a roughly equal mass to the ocean at its perimeter by melting and calving icebergs. In Antarctica, for instance, some 90 percent of the ice that reaches the sea is carried there by ice streams, giant conveyor belts of ice as thick as the surrounding sheet (between 3,500 and 6,500 feet) and 60 miles wide, extending more than 500 miles "upstream" from the sea. Ice streams moving through an ice sheet leave crevasses at their sides as they lurch forward. Near

MAPPING SPECIALISTS

[THE CONSEQUENCES]

Inundation from the Ice Sheets

If today's ice sheets disappear, the resulting rise in global sea level would transform coastlines around the world; the effects on the Florida coastline are shown below. Actually, if climate change caused one ice sheet to disappear, parts of others would do so as well, and the effects on sea level would be even greater than what is depicted here.



▲ **West Antarctic ice sheet** holds enough ice to raise sea level globally by **19 feet**. Coastal and south Florida would be flooded.

▲ **Greenland ice sheet** is the equivalent of **24 feet** of global sea level. Flooding in Florida would be similar to the West Antarctic case.

▲ **East Antarctic ice sheet** could raise sea level globally by **170 feet**. Virtually the entire state of Florida would be underwater.

the seaward margins of the ice sheet, ice streams typically move between 650 and 3,500 feet a year; the surrounding sheet hardly moves at all.

But long-term ice equilibrium is an idealization; real ice sheets are not permanent fixtures on our planet. For example, ice-core studies suggest the Greenland ice sheet was smaller in the distant past than it is today, particularly during the most recent interglacial period, 120,000 years ago, when global temperatures were warm. In 2007 Eske Willerslev of the University of Copenhagen led an international team to search for evidence of ancient ecosystems, preserved in DNA from the base of the ice sheet. His group's findings revealed a Greenland that was covered with conifers as recently as 400,000 years ago and alive with invertebrates such as beetles and butterflies. In short, when global temperatures have warmed, the Greenland ice sheet has shrunk.

Today the snowfall on top of the Greenland ice cap is actually increasing, presumably because of changing climatic patterns. Yet the mass losses at its edges are big enough to tip the scales to a net decline. The elevation of the edges of the ice sheet is rapidly declining, and satellite measurements of small variations in the force of gravity also confirm that the sheet margins are losing mass. Velocity measurements indicate that the major outlet glaciers—ice streams bounded by mountains—are accelerating rapidly toward the sea, particularly in the south. The rumblings of glacial earthquakes have become increasingly frequent along the ice sheet's outlet glaciers.

Like the Greenland ice sheet, the West Antarctic ice sheet is also losing mass. And like the Greenland ice sheet, it disappeared in the geologically recent past—and, presumably, could do so again. Reed P. Scherer of Northern Illinois University discovered marine microfossils at the base of a borehole in the West Antarctic ice sheet that only form in open marine conditions. The age of the fossils showed that open-water lifeforms might have lived there as recently as 400,000 years ago. Their presence implies that the West Antarctic ice sheet must have disappeared during that time.

Only the ice sheet in East Antarctica has persisted through the earth's temperature fluctuations of the past 30 million years. That makes it by far the oldest and most stable of the ice sheets. It is also the largest. In many places its ice is more than two miles thick, and its volume is roughly 10 times that of the ice sheet in Greenland. It first formed as Antarctica drew apart from South America some 35 million years ago and global levels of carbon dioxide declined. The East Antarctic ice sheet appears to be growing slightly in the interior, but observers have detected some localized losses in ice mass along the margins.

Accelerating Losses

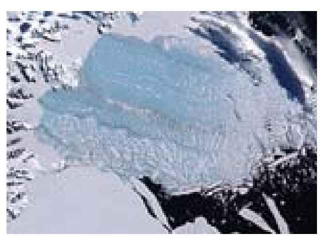
What processes could lead to the net mass losses observed today in the ice sheets of Greenland and the West Antarctic? As one might expect, the losses in both ice sheets ultimately stem from a speedup of the ice streams and outlet glaciers that convey mass to the oceans. The extra water volume displaced by that extra ice mass, of course, is what causes global sea level to rise. (It is probably worth mentioning that the breakup or melting of floating ice shelves has no net effect on sea level. The reason is that floating ice displaces a volume of water equal to its own weight; when it melts, its weight does not change, but its new, smaller volume now fits exactly into the same volume that it displaced when it was ice.)

In the past five years investigators have developed two important new insights about the processes that can trigger accelerating flows. First, an ice stream can speed up quite suddenly as its base encounters mud, meltwater or even deep lakes that intermittently grease its way. Second, if seagoing ice shelves (floating in the Southern Ocean around Antarctica) or ice tongues (long but narrow ice shelves linked to single outlet glaciers, common in the fjords of Greenland) break up, their enormous masses no longer hold back the flow of ice streams. The glaciers feeding the Larsen B ice shelf, for instance, accelerated dra-

THE BREAKUP OF LARSEN B

Satellite images record the sudden breakup of a Rhode Island–size segment of an ice shelf off the Antarctic Peninsula known as Larsen B. The small dark regions on the ice surface in the upper image (*below*) are ponds of meltwater that formed in unusually warm air; the light-blue region in the bottom image is made up of the fragments of the original ice-shelf segment.

January 31, 2002

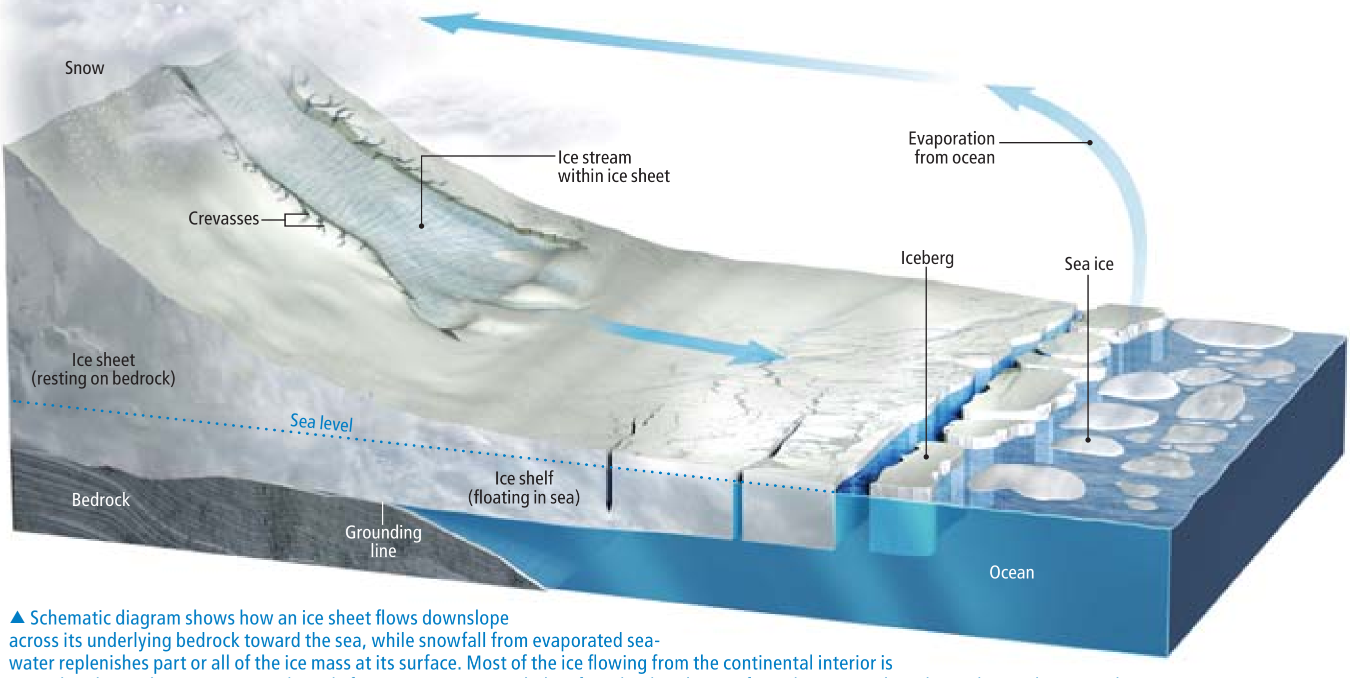


March 7, 2002

MAPPING SPECIALISTS (*Florida maps*); NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO (*Larsen B images*)

[ICE MOVEMENT 101]

Steady State in a Frozen Country



▲ Schematic diagram shows how an ice sheet flows downslope across its underlying bedrock toward the sea, while snowfall from evaporated seawater replenishes part or all of the ice mass at its surface. Most of the ice flowing from the continental interior is carried to the sea by ice streams, relatively fast-moving conveyor belts of ice that break away from the surrounding sheet; the ice sheet travels seaward as well, albeit much more slowly. Once the base of the moving ice leaves its "grounding line," the floating ice is called an ice shelf, and it displaces a mass of water equal to its weight, raising the sea level accordingly. Throughout most of the past several millennia those processes did not raise sea level or shrink ice sheets because seawater evaporation and inland snowfall roughly balanced the discharge of ice into the sea.

matically after the ice shelf disintegrated in 2002. Thus "uncorked," the land-based ice streams and glaciers that were formerly held in check will likely speed their seaward migration, ultimately adding to the total volume of the sea.

Glaciologists have long recognized a third kind of trigger for accelerating ice-sheet flow, which is closely related to the second. Just as glaciers sped up when Larsen B disintegrated, an ice sheet accelerates if warm ocean currents thin an ice shelf into which the ice sheet flows. In the Amundsen Sea sector of West Antarctica, the surface of the ice sheet has dropped by as much as five feet a year and the sheet has sped up by 10 percent, both apparently in response to the thinning of the ice shelf.

"Greasing the Skids"

The breakup of the Larsen B ice shelf and the equally alarming association between the sudden drainage of surface water in Greenland and accelerating flows in the ice sheet have prompted a number of my colleagues and me to focus our studies on the role of liquid water within the ice sheets. We are finding that liquid water has helped the seaward ice movement keep pace with interior snowfall, maintaining the dynamic equilibrium of the ice sheets in some cases for millions of years. In West Antarctic ice streams, for instance, lubricating water melts out of the ice at the base of the ice sheet because of the heat from friction between moving ice and the underlying rock. In East Antarctica water melts at the base of the ice sheet primarily because of heat from the underlying continental crust. The ice is so thick in the East Antarctic that it acts as an insulating blanket, capturing the geothermal heat. All that subglacial water introduces enormous potential for instability in the ice movements. Events such as the breakup of Larsen B are far more likely than glaciologists ever thought possible to accelerate the flow rates of upstream ice.

The idea that the base of the ice sheets could melt first arose in 1955, when Gordon Robin suggested that geothermal heat could lead to extensive subglacial water, provided the overlying ice sheet was thick enough to insulate its base from its cold surface. But his suggestion was not confirmed until the 1970s and then in a startling way. By that time, ice-penetrating radar had been developed to the point that it could "see" through an ice sheet to the underlying surface. Robin organized an American, British and Danish team to collect such radar data from aircraft flown back and forth over the Antarctic conti-

[THE AUTHOR]

Robin E. Bell is director of the ADVANCE program at the Earth Institute at Columbia University. She is also a Doherty Senior Research Scientist at Columbia's Lamont-Doherty Earth Observatory, where she directs a major research program in Antarctica. Bell studies the mechanisms of ice-sheet collapse, as well as the chilly environments underneath the Antarctic ice sheet, and she has led seven expeditions to Antarctica. She is chair of the Polar Research Board of the National Academies and has served as vice chair of the International Planning Group for the International Polar Year.

BRUCE GILBERT/EARTH INSTITUTE (*Bell*); KEVIN HAND (*illustration*)

nent. Most of the time the radar return signals on the onboard oscilloscope were irregular, as one would expect for signals bouncing off hills and valleys covered by thick ice. In some places, though, it looked as if someone had drawn a straight line across the oscilloscope. The radar energy was being reflected by a surface more like a mirror. Having begun his career as a sailor, Robin concluded that the mirrorlike surface must be water underneath the ice sheet. The radar data showed that some of the subglacial "mirrors" continued for almost 20 miles, but Robin had no sense of their true scale or depth.

Once more, Robin had to wait almost two decades for new technology. In the 1990s the European Space Agency completed the first comprehensive mapping of the ice surface. Looking at the image, one is instantly struck by a flat region in the center of the ice sheet. Some two miles above the water, Vostok Station, the Russian Antarctic base, looks onto an ice surface that outlines the flat contours of the lake. The size of Lake Vostok now became obvious; it is as big as Lake Ontario.

Subglacial Plumbing

The discovery of subglacial lakes has fundamentally changed the way investigators think about water underneath the ice. It is not rare but rather both abundant and widespread. More than 160 subglacial Antarctic lakes have been located so far. Their combined volume is nearly 30 percent of the water in all the surface lakes elsewhere on the planet. My studies of East Antarctica's Lake Vostok in 2001 revealed a fairly stable system. In the past 50,000 years the lake water has slowly exchanged with the overlying ice sheet through melting and freezing. Of course, in the more distant past things might not have been so quiescent: geologic evidence shows that subglacial lakes can drain out suddenly, in a single belch, releasing tremendous amounts of water under the ice sheet or directly into the ocean. Immense valleys more than 800 feet deep (enough to swallow the Woolworth Building in New York City) encircle the entire Antarctic continent: the scars from giant floods.

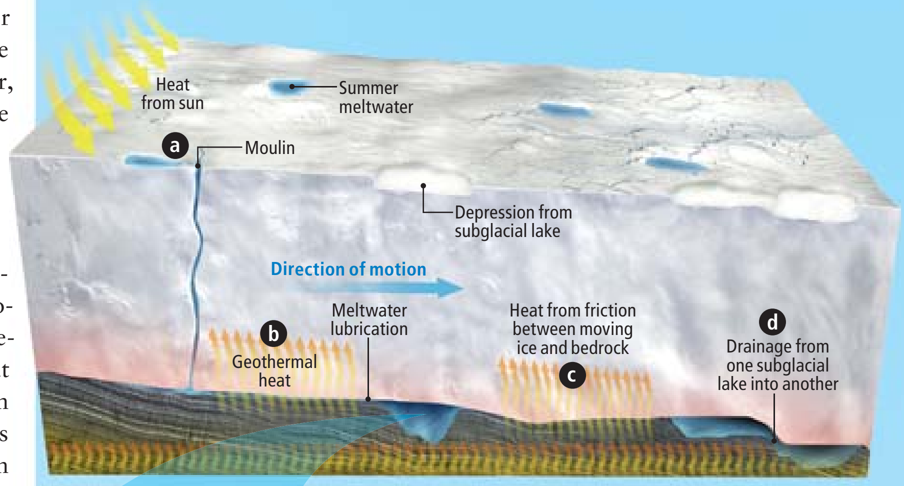
But Vostok and the other subglacial lakes were

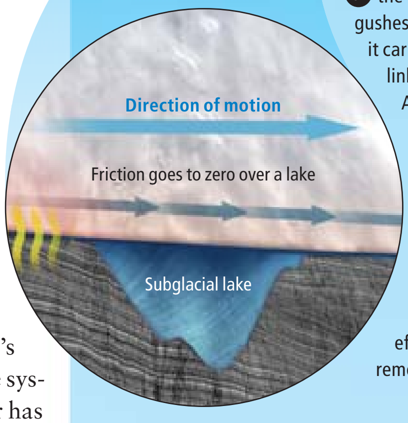
For an animated movie of one subglacial lake draining into another, check out http://svs.gsfc.nasa.gov/search/Scientist/HelenAmandaFricker.html

[DISTURBING EQUILIBRIUM]

Not So Steady, Not So Frozen

Newly discovered networks of liquid water in and under ice sheets may make the ice far less stable than investigators previously thought—and far more sensitive to the effects of global warming.



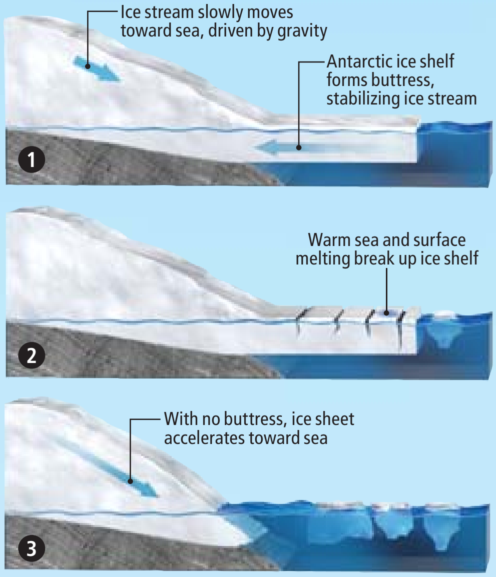


▲ Slippery Slope

Water under the ice, no matter how it gets there, can lubricate the contact between bedrock and the bottom of an ice sheet. In Greenland (a) the warming Arctic climate has led to surface meltwater that gushes into crevasses, or moulins, and drains along with the solar heat it carries to the base of the ice sheet. The drainage has been strongly linked to the acceleration of ice movement toward the sea. In Antarctica, drainage of surface meltwater is relatively unimportant to ice-sheet movement, but water accumulates at the base of the ice sheets in other ways. It melts out of the bottom of the ice from geothermal (b) or frictional heat (c) that is trapped by the insulating thickness of the ice itself. It is also present as an extensive system of subglacial rivers and lakes that drain into one another (d). In Antarctica the water at the base of the ice sheets is almost entirely isolated from the direct, short-term effects of global warming, but its lubricating effect makes the sheets sensitive to any disturbance that could remove impediments, such as buttressing ice shelves, to their flow.

▶ Help! I'm Losing My Buttress!

Slippery ice streams, particularly in West Antarctica, would likely slide rapidly into the sea under gravity if it were not for the bracing effect of the floating ice shelves that surround the continent (1). Relatively warm air and ocean water in recent years, however, have caused ice shelves to thin and, in the case of Larsen B, to break up (2). With its buttress gone, a moving ice stream is no longer prevented from crashing into the sea and causing a rapid rise in sea level (3).



KEVIN HAND

INTERNATIONAL POLAR YEAR

When the Larsen B ice shelf collapsed in March 2002, polar scientists realized that their timetable for action on global warming would be measured in months and years, not decades. Work began at once to organize the fourth International Polar Year (IPY), which runs through March 2009. More than 50,000 scientists from more than 60 nations have joined the effort to understand the polar environments. Here are some of the most important antecedents to the IPY:

1872–1874 Austro-Hungarian North Pole expedition, co-commanded by Karl Weyprecht

1882–1883 Weyprecht's dream of coordinated international cooperation in polar study is realized in the first International Polar Year (IPY)

1911 Roald Amundsen's expedition is the first to reach the South Pole

1912 Robert Falcon Scott's expedition reaches the South Pole just weeks after Amundsen's; Scott's party perishes on the return trip

1914–1916 Ernest Shackleton's trans-Antarctic expedition is trapped in ice, then dramatically rescued

1932–1933 Second IPY

1957–1958 International Geophysical Year (third IPY)

2002 Collapse of the Larsen B ice shelf

2007–2009 Fourth IPY

thought to be natural museums, isolated from the rest of the world millions of years ago. Then in 1997 the first hint that such subglacial flooding still takes place came from West Antarctica. The surface of the ice sheet sagged by more than 20 inches in three weeks. The only explanation that made any sense was that water was draining out of a subglacial lake, causing the overlying ice to sink. A group led by Duncan J. Wingham of University College London also measured elevations for that year over most of the East Antarctic ice. In one area the ice sheet sagged about 10 feet in 16 months, while 180 miles downslope two areas rose by about three feet. Once again, the explanation was obvious: a subglacial river had drained the water from one lake and filled two lakes downstream.

A little more than a year ago Helen A. Fricker of the Scripps Institution of Oceanography in La Jolla, Calif., was studying the precise measurements of surface elevations made by the ICESat spacecraft. Just before Fricker left for a Memorial Day weekend of sailing with her family, one of the profiles over the ice sheet diverged radically. A region along the margin of one of the largest West Antarctic ice streams had collapsed—a fall of nearly 30 feet in 24 months. Returning from her weekend, Fricker examined the ice surface surrounding her new lake, Lake Engelhardt—and quickly realized that it was only one in a series of cascading subglacial lakes. Large quantities of water draining through the plumbing system underneath major ice streams have turned out to be one more agent of rapid change in the flow of an ice stream.

Lake Effect

At about that same time, suspecting that subglacial lakes could affect ice-sheet stability, I realized that new satellite imagery made it easy to spot such lakes. Furthermore, models of the ice sheet predicted that one more set of large lakes might still remain to be discovered. I was intrigued by the chance to find them. So with the help of the new imagery and ICESat laser data, my colleagues and I discovered four new subglacial lakes, three of them larger than all the other lakes except Vostok.

Compared with subglacial rivers and collapsing lakes, though, "my" four new lakes were simply boring. All the exciting new results in my field were focusing on rapidly changing polar ice and the potential for ice sheets to raise sea level. Still, the lakes kept nagging me. They were far from the center of the ice sheet, where most large

JAMES BALOG *Aurora Photos*

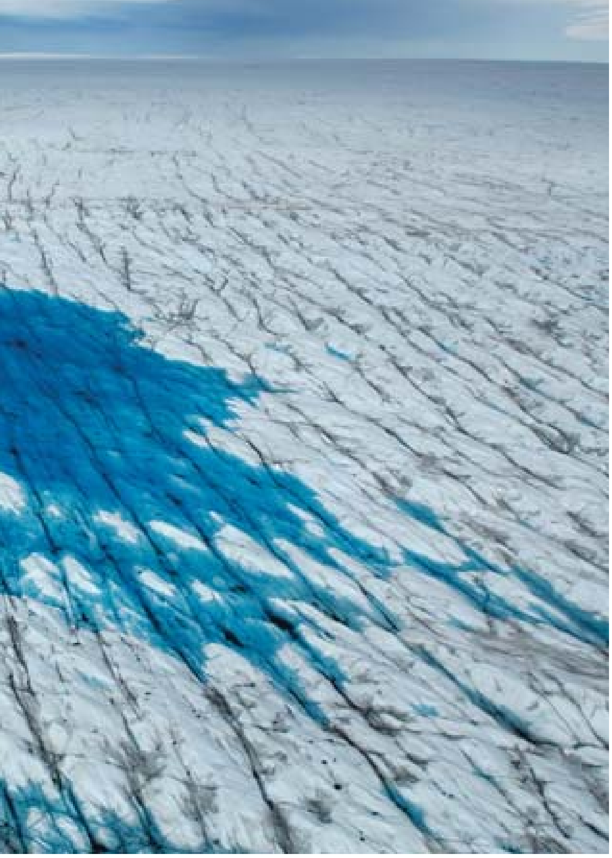
lakes occur. Crevasses and cracks in the ice formed along the edges of one lake; I could see the crevasse fields in satellite images.

Crevasses, as I mentioned earlier, form when an ice stream moves rapidly forward within an ice sheet. Looking at the imagery, I could see flow lines in the ice sheet, which connected the region of crevasses to a fast-flowing ice stream known as Recovery. Satellite interferometry showed that the Recovery ice stream begins accelerating at the lakes. Before the ice sheet crosses the lakes, its velocity is no more than about 10 feet a year. On the other side of the lakes the ice sheet accelerates to between 65 and 100 feet a year. So the lakes appear to be triggering the flow of an ice stream within the ice sheet. The finding is the first time subglacial lakes have been directly linked to accelerated surface flow.

My colleagues and I are still not certain exactly why the linkage occurs at all. Perhaps the lakes are slowly leaking out of their basins, thereby supplying water to lubricate the base of the ice sheet. Or the lake water might warm the base of the ice sheet as it crosses the lake, making it easier for the ice sheet to speed up on the far side of the lake.

International Polar Year

The understanding of water in the ice sheets and subglacial lakes has changed dramatically in the past two years. But that understanding is by no means complete. One of the major goals of the International Polar Year is to gauge the status of



▲ ABUNDANCE OF SURFACE WATER **melted by warm air above the Greenland ice sheet is dramatically portrayed in these two photographs. The summer ice surface has become dotted with lakes, such as the one above left—several hundred yards across—and riven with crevasses. A torrent of meltwater pours into a moulin, a deep opening in the ice (*above*), and drills its way to the bottom of the ice sheet, where it helps to speed the ice flow. The floating ice shelves of Antarctica are also accumulating surface meltwater.**

the polar ice sheets and determine how they will change in the near future. The recent report by the Intergovernmental Panel on Climate Change (IPCC) emphasizes that the biggest question mark in predicting the effects of global warming is the uncertainty about the future of the polar ice sheets. None of the climate models used to date takes account of such major features as ice streams, and none of them incorporates an accurate representation of the bottom of an ice sheet.

For those reasons alone, predicting future sea-level change from the current climate models greatly underestimates the future contribution of the polar ice sheets to sea-level rise. But updating the models by quantifying the ice movements still demands intensive research efforts. Simply, if glaciologists do not know what goes on at the bottom of the ice sheets, no one can predict how ice sheets will change with time. And the key questions for making such predictions are: Just where is the subglacial water? How does it move? How does it affect the movement of the ice sheets?

The IPY offers an excellent opportunity to find out. By mobilizing international scientific teams and logistics, investigators will be able to deploy a new generation of airborne radar for mapping subglacial water. New gravity instrumentation, originally developed for the mining industry, will be adapted to estimate the volume of water in the subglacial lakes. Precise elevation measurements of the ice surface will enable water movement to be monitored. Newly installed seismometers will listen for glacial earthquakes.

In Greenland, glaciologists will install instruments to measure the movement of the ice sheet through the major outlet glaciers. The Center for Remote Sensing of Ice Sheets in Lawrence, Kan., will deploy an unmanned airborne vehicle to systematically map the water at the base of the ice sheet. In East Antarctica, my group will fly a Twin Otter (a two-engine, propeller-driven plane) over the Recovery lakes and the unexplored Gamburtsev Mountains to understand why the lakes form and how they are triggering the ice stream. At the same time, a U.S.-Norwegian team, including Ted Scambos, will cross the Recovery lakes, measuring the velocity of the ice sheet and its temperature gradient along the top. A Russian team will seek to sample Lake Vostok; an Italian team will study Lake Concordia, near the French-Italian station in East Antarctica; and a British team will survey a lake in the Ellsworth Mountains in West Antarctica.

All those efforts—in conditions that remain daunting to human work—reflect the consensus and urgency of the international scientific community: understanding the changing ice sheets and the water that governs their dynamism is crucial to the future of our society. ■

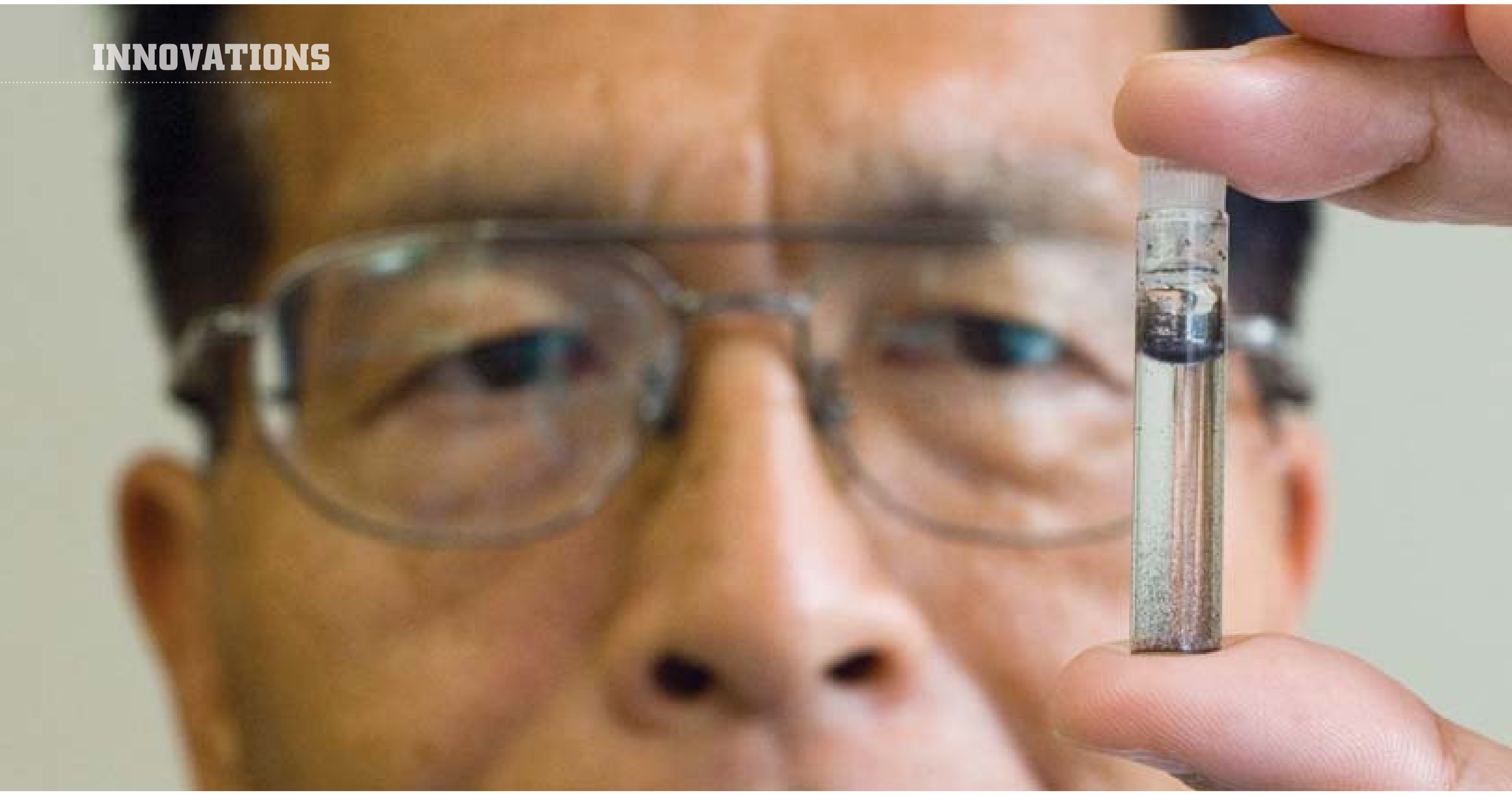
➡ MORE TO EXPLORE

Glaciology: Lubricating Lakes. Jack Kohler in *Nature,* Vol. 445, pages 830–831; February 22, 2007.

Large Subglacial Lakes in East Antarctica at the Onset of Fast-Flowing Ice Streams. Robin E. Bell, Michael Studinger, Christopher A. Shuman, Mark A. Fahnestock and Ian Joughin in *Nature,* Vol. 445, pages 904–907; February 22, 2007.

An Active Subglacial Water System in West Antarctica Mapped from Space. Helen Amanda Fricker, Ted Scambos, Robert Bindschadler and Laurie Padman in *Science,* Vol. 315, pages 1544–1548; March 16, 2007.

Ice Sheets. Charles R. Bentley, Robert H. Thomas and Isabella Velicogna. Section 6A in *Global Outlook for Ice and Snow,* pages 99–114; United Nations Environment Programme, 2007. Available at **www.unep.org/geo/geo_ice**



TIM HORNYAK

RFID Powder

KEY CONCEPTS

- Radio-frequency identification (RFID) tags, an electronic alternative to bar codes, are becoming increasingly common. They mark shipping pallets and library books, for example, and are key to remote toll-paying systems.
- Hitachi, which already produces a tiny chip for use in such tags, has announced a prototype for an almost invisible chip.
- The company intends for the new chip to be incorporated into high-value vouchers—such as gift certificates, tickets and securities—to thwart counterfeiters.

—The Editors

More than 22 million visitors attended the Expo 2005 World's Fair in Aichi, Japan. Not one got in with a bogus ticket. The passes were practically impossible to forge because each harbored a tiny RFID (radio-frequency identification) chip—just 0.4 millimeter (mm) on a side and 0.06 mm thick—that transmitted a unique identification number via radio waves to a scanner at the gates.

Now Hitachi, the maker of that chip, is aiming even smaller. Last year it announced a working version of a chip only 0.05 mm on a side and 0.005 mm thick. Almost invisible, this prototype has one sixty-fourth the area yet incorporates the same functions as the one in the Expo tickets. Its minuteness, which will allow it to be embedded in ordinary sheets of paper, heralds an era in which almost anything can be discreetly tagged and read by a scanner that it need not touch.

In Tokyo the chip's designer, Mitsuo Usami of Hitachi's Central Research Laboratory, holds up a small vial of liquid, points to a swirl of particles inside it and smiles. They glitter like stardust in the afternoon sunlight. "This is the smallest chip of its kind in the world," he enthuses.

The Allure of the Small

Even before this size breakthrough, RFID tags (combining chips with antennas) were being touted as a revolutionary force in the supply chain. Despite costing more than bar codes, they are seen as a more efficient alternative to those familiar line patterns; a good RFID tag does not have to be scanned manually or oriented in a certain way to be readable. Major retailers such as Wal-Mart have introduced them in recent years with an eye to saving billions on inventory and labor costs. Other growing applications include electronic toll collection, public transit passes and passports; some people have even implanted the devices in their hands to allow easy access to home and computer.

But Hitachi's main goal for the new chip is use in anticounterfeiting technology. It could be embedded in high-value vouchers such as securities, concert tickets, gift certificates and cash. Usami and his colleagues believe that the smaller the chip, the more easily it can be seamlessly buried. "As sophisticated high-tech gear becomes cheaper and cheaper, it's easier to forge things made out of paper," Usami says. "Even

MITSUO USAMI of Hitachi shows off a vial containing thousands of the minuscule chips (*black specks*) he invented for use in radio-frequency identification (RFID) tags.

Radio-frequency identification tags label all kinds of inventoried goods and speed commuters through toll plazas. Now tiny RFID components are being developed with a rather different aim: thwarting counterfeiters **By Tim Hornyak**

though e-money is getting popular, bank notes are still very convenient."

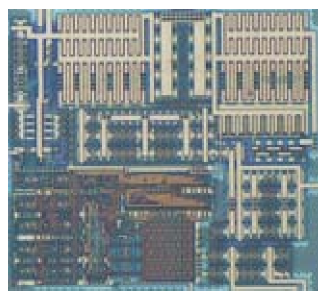
Like other "passive" RFID chips, the one that was used at the Aichi Expo—known as the μ-Chip (pronounced "mew chip")—operates simply and requires no batteries or power supply. When it is embedded in an item along with an attached antenna (usually a filamentlike strip), it will respond to 2.45-gigahertz microwaves from a scanner by reflecting back a unique 128-bit ID number stored in its read-only memory (ROM). The scanner then checks the number against a database—which can be anywhere in the world—to immediately authenticate the item containing the chip.

Hitachi says the μ-Chip can be used to identify "trillions of trillions" of objects, because the 128-bit architecture affords an almost infinite number of digit combinations: 10^{38}. Each unique ID number is meaningless in itself, but when matched to a database entry it will call up whatever information the user has assigned to the chip. The smaller chip under development, officially called the Powder LSI chip, also stores a 128-bit identifier. ("LSI" stands for "large-scale integrated.")

Both the μ-Chip and the powder version grew out of a vision Usami, a veteran circuit engineer, sketched out after seeing an ad for the "i-mode" cell phones that Japanese telecom giant NTT introduced in 1999. These pioneering devices allowed users to access the Internet through a handset. Usami imagined a network of tiny RFID chips and servers: RFID chips would be attached to small devices and would essentially be empty except for a unique identity number that would be conveyed to a server. Having received a valid number, the server would provide the various functions a person might want to use. The notion is similar to "cloud computing" of today, in which applications that would otherwise be stored on an individual's computer reside elsewhere and are accessed through the Internet.

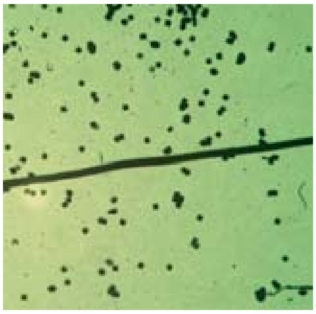
Usami therefore turned his attention to creating an RFID chip that would be small enough to incorporate in anything. To be marketable, it also had to be inexpensive, simple and secure. He already knew something about developing diminutive chips. Earlier in the 1990s he had designed an ultrathin telephone card that was embedded with a microchip instead of having a magnetic strip, because the chip could provide security through encryption. The embedded chip was 4 mm on a side and 0.25 mm thick.

But Usami wanted to go smaller. First he had to figure out the minimum functions a chip would need to perform. He turned to colleague Kazuo Takagi, a computer security specialist at Hitachi's Systems Development Laboratory, for help. After the two discussed the problem at length, Usami decided that using just a 128-bit ID number would enable him to keep the design very simple yet still provide a very high number



POWDER CHIP surface is shown at roughly 800 times its true size.

COURTESY OF HITACHI LTD. CENTRAL RESEARCH LABORATORY



MINUTENESS of powder chips is evident in a micrograph showing a single hair from a Japanese woman surrounded by silicon bits the size of those chips.

of digit combinations. At the same time, the approach would ensure security because the information stored in the read-only memory would be unchangeable. He also stripped out all inessentials, leaving behind, aside from the ROM, a simplified radio-frequency circuit (to interact with the antenna), a rectifying circuit (to manage current flow) and a clock circuit (to synchronize the chip's activities and coordinate them with a scanner).

Ironically, Usami's biggest challenge in realizing a shrunken microchip was nontechnical. Then, as now, conventional chip development favored ever increasing memory and functionality, so Usami was swimming against the current with his stripped-down design. Hitachi's business division was deeply opposed, wanting the chip to incorporate rewritable encryption features. Without the division's financial support, his idea would never get off the drawing board.

But an unexpected white knight intervened. Shojiro Asai, then general manager of Hitachi's R&D Group, recognized the project's potential. He said he would fund prototype production of what became the μ-Chip (named for the Greek letter in the micron symbol, μm) on the condition that Usami recover all costs. Offering the chip for counterfeit protection did the trick. Its success at the Aichi Expo in 2005 convinced Hitachi to allow Usami to keep shrinking his creation.

Making Powder

Powder chips have essentially the same components as the μ-Chip, but these are snuggled into a smaller space. One key to the extra miniaturization was employing what is called 90-nanometer silicon-on-insulator (SOI) technology, a method of advanced chipmaking pioneered by IBM and now being used by others. SOI makes processors that perform better and consume less power than those produced by conventional methods because it isolates transistors with an insulator. The insulator both reduces the absorption of electrical energy into the surrounding medium—boosting signal strength—and keeps the transistors separate. Separation in this way prevents interference between transistors and allows them to be packed more closely together, which makes it possible for chip size to shrink.

Electron beam lithography helped as well. This technology wields a focused beam of electrons to produce a unique wiring pattern that represents a chip's individual ID number in a compact area. Electron beam lithography lays down circuit patterns more slowly than photolithography does, because it generates patterns serially instead of in parallel. Hitachi, though, developed a method that produces powder chips 60 times faster than the μ-Chip is made.

RFID tags typically consist of chips and external antennas, and the same is true of the μ-Chip. For certain applications, though, μ-Chips and the powder form will need an internal antenna, one embedded right on the chip. But those reduce how far away a scanner can be. The maximum scanning distance for Hitachi's commercial μ-Chips with external antennas is currently 30 cm (about a foot), and the range of the powder prototype is the same—short but acceptable for most applications involving money or securities. The company is doing research aimed at extending the range of both external and internal antennas. The application will determine the range required: money or securities would require only a few millimeters or a centimeter, whereas package sorting would require a range of about one meter. The firm is also working on "anticollision" technology that would allow the simultaneous reading of multiple chips, such as when goods sit together on a store shelf or are jumbled in a shopping basket.

[SCENARIO]

A Likely Use for Powder Chips

Hitachi's bare-bones, powder RFID chip could be embedded in money, securities, tickets and such to thwart counterfeiters. Imagine a clerk

[THE AUTHOR]

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GREG McCARTNEY *Prime Light Photo (Hornyak)*; COURTESY OF HITACHI LTD. CENTRAL RESEARCH LABORATORY *(powder chips)*

wanting to verify that a $100 bill is real. The clerk would pass the bill near a scanner. The scanner would detect the unique ID number stored in the chip (*1–3*) and send it to a database of bill numbers (*4*), which would indicate whether the money was legitimate (*5*).

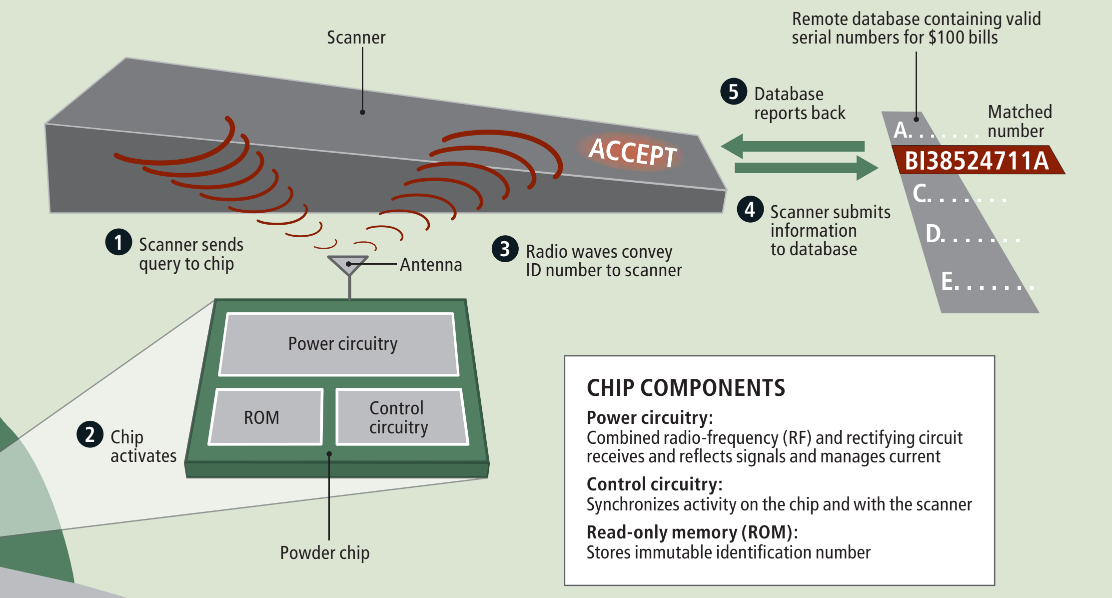


Diagram is schematic and not to scale.

RELATIVE SIZES

A standard chip in a "passive" RFID tag (one that has no battery) affixed to a library book might measure one to two millimeters on a side (like the cross section of lead in an unsharpened number 2 pencil). Hitachi's μ-Chip is less than a quarter that size in area, and the powder chip is some 64 times as tiny as the μ-Chip.

Magnification

Chip in library tag
Actual size:
1 mm × 1 mm × 0.18 mm

μ-Chip
Actual size:
0.4 mm × 0.4 mm × 0.06 mm

Powder chip
Actual size:
0.05 mm × 0.05 mm × 0.005 mm

For visibility, the representations above are about 10 times actual size.

Little Brother?

Although putting chips into money is a logical application for minute RFID chips, chipped cash could exacerbate privacy concerns surrounding the use of RFID technology. It raises the specter, for instance, of an unscrupulous person scanning the contents of another's wallet from far away. Choosing tags requiring a short-range scanner, such as the readers in ATM machines, would limit such intrusion, however. And the criminal would also need access to the right server and database for the information to have any meaning.

The infinitesimal size of the Powder LSI chips under development also helps to conjure sci-fi scenarios. Could police, say, spray the powder on a crowd of rioters and then trace them afterward through security scanners distributed along roads or in public transit? Hitachi asserts that it is infeasible to deploy the chips by sprinkling them—they must be attached to antennas to function. And, Usami says, "many civic groups have developed guidelines to protect privacy with RFID. A fundamental guideline for this technology is that it not be used surreptitiously."

The *Guardian* newspaper in London, though, has already documented a case in which the supermarket chain Tesco tested selling Gillette razor blades packaged with RFID tags able to trigger a hidden camera if theft were attempted. Although privacy advocates may recognize the shipping and supply benefits of RFID, they want to be able to remove or turn off the tags once an item has been purchased.

Usami thinks the potential benefits of RFID outweigh the risks. "For example, embedding sidewalk tiles or crosswalks with RFID tags could help autonavigation systems in wheelchairs. This is important especially in Japan, which has an aging society." Even as paper use diminishes, tiny RFID chips will come in handy in situations where size, access and complexity are constraining factors. As an example, Hitachi envisions using the powder chips to reduce the time it takes to install and verify complex electrical wiring systems at companies, factories and other facilities. Cables and terminals would be equipped with chips so workers could quickly check them against a database and the related schematics instead of relying on lengthy visual inspections.

But if privacy advocates have concerns about chips becoming harder and harder to find, that particular fear is real: Usami says the miniaturizing trend will continue. ■

MELISSA THOMAS

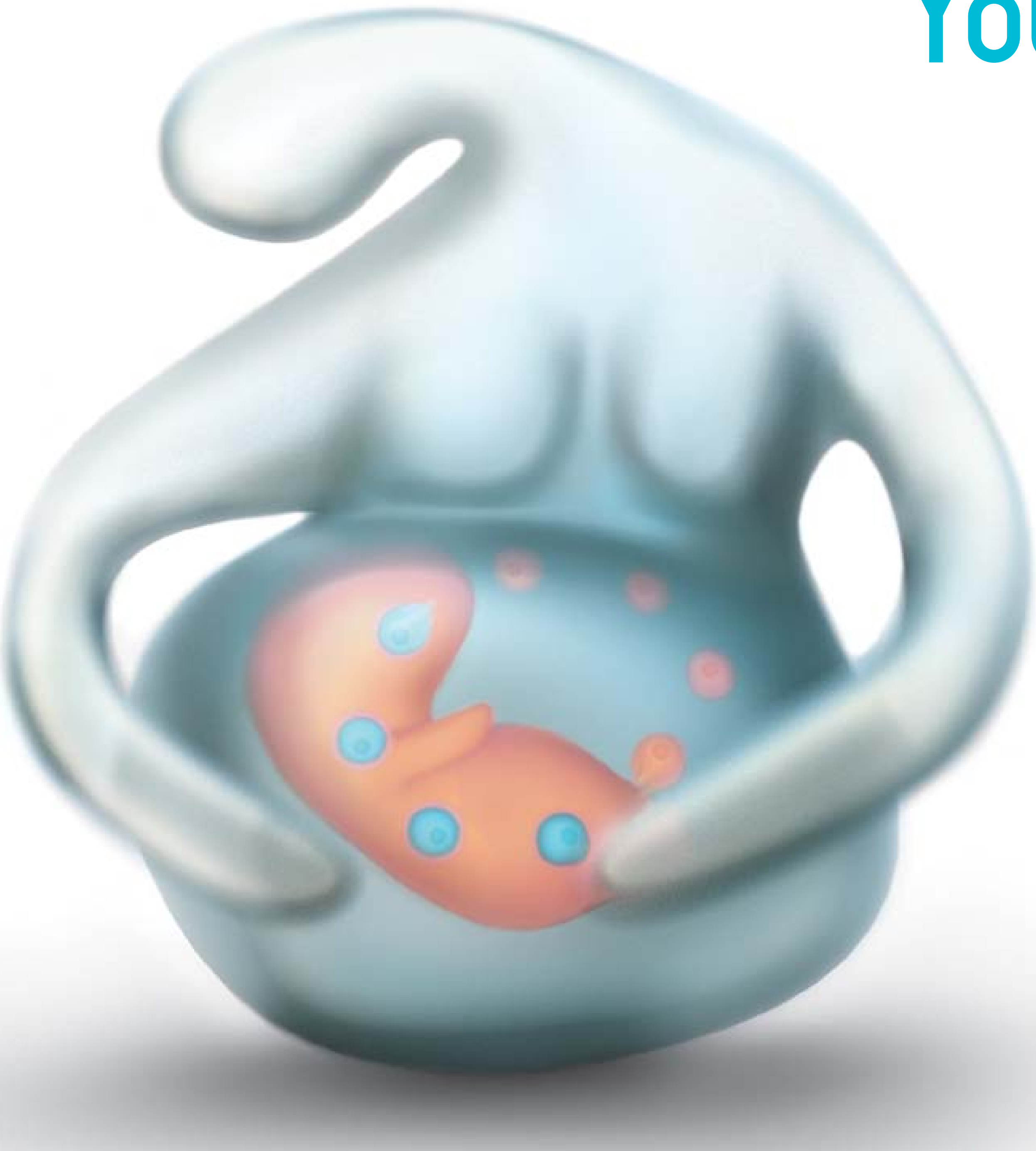
MORE TO EXPLORE

RFID: A Key to Automating Everything. Roy Want in *Scientific American*, Vol. 290, No. 1, pages 56–65; January 2004.

Hitachi Achieves 0.05-mm Square Super Micro RFID Tag, "Further Size Reductions in Mind." Available at **http://techon.nikkeibp.co.jp/english/NEWS_EN/20070220/127959/**

RFID Journal: **www.rfidjournal.com**

Your



Cells  Are My Cells 

Many, perhaps all, people harbor a small number of cells from genetically different individuals—from their mothers and, for women who have been pregnant, from their children. What in the world do these foreigners do in the body? BY J. LEE NELSON

"I contain multitudes," says a line in Walt Whitman's poem "Song of Myself." Whitman was not thinking in biological terms, but the line has biological resonance. Recent studies suggest that each of us possesses—in addition to the trillions of cells descended from the fertilized eggs we once were—a cadre of cells we have acquired from other, genetically distinct individuals. In utero we receive an infusion of them from mom. And women who become pregnant also collect a sampling shed by the developing embryo.

That cells cross the placenta is not surprising. After all, the tissue that connects mother and child is not an impenetrable barricade. It is more like a selective border crossing, allowing passage, for instance, of materials needed for the fetus's development. What is remarkable, however, is the extent to which migrant cells can persist in their new host, circulating in the blood and even taking up residence in various tissues. The intermingling of some cells from one person inside the body of another—a phenomenon termed microchimerism—is now drawing intense scrutiny from medical researchers, because recent work suggests it may contribute to both health and disease. Better understanding of the actions of the transferred cells could someday allow clinicians to harness the stowaways' beneficial effects while limiting their destructive potential.

Surprise after Surprise

Scientists gleaned early hints that a mother's cells could pass to her fetus almost 60 years ago, when a report described the transfer of mater-

BRYAN CHRISTIE DESIGN

TWO-WAY TRANSPORT: **During pregnancy, some cells travel from mother to baby and some go from baby to mother. A fraction may persist in their new host. The condition is termed microchimerism.**

KEY CONCEPTS

- Recent research suggests that each of us harbors some cells that originated in other, genetically distinct individuals—a condition called microchimerism. All of us probably save cells we have acquired from our mother during gestation, and women who have been pregnant retain cells that come from the fetus.
- The acquired cells can persist for decades and may establish residence inside tissues, becoming an integral part of the body's organs.
- Microchimerism could contribute to an immune attack in some cases but help the body heal in others. These effects make the acquired cells intriguing new targets for therapeutics that could curb autoimmunity or promote regeneration of damaged tissues.

—The Editors

nal skin cancer cells to the placenta and the infant. By the 1960s biologists began recognizing that normal maternal blood cells can also find their way to the fetus.

Data suggesting that cells flow in the other direction as well—from fetus to mother—date back even further, to 1893, when a German pathologist discovered signs of such transfer in lungs of women who had died from a hypertensive disorder of pregnancy. Yet the acquisition of fetal cells by healthy mothers was not well documented in humans until 1979, when a landmark paper by Leonard A. Herzenberg of the Stanford University School of Medicine and his colleagues reported finding male cells (those with a Y chromosome) in blood from women who were pregnant with boys.

Despite evidence of two-way cellular traffic between mother and fetus, biologists were surprised in the 1990s when they learned that small numbers of the foreign cells often survive indefinitely in healthy individuals. Earlier studies of mother-to-child transfer had shown that maternal cells could survive in children with severe combined immunodeficiency, a disorder in which afflicted individuals lack critical infection-fighting cells. But scientists had assumed that the ongoing microchimerism in these children stemmed from their disease and that a normal immune system would destroy any maternal cells lurking in a child.

That thinking changed when my colleagues and I found maternal cells in adults who had a normal immune system, including in one person aged 46. Evidence that fetal cells can likewise persist in mothers came some years earlier, when Diana W. Bianchi of Tufts University found male DNA in women who had given birth to sons decades before. (In many studies, investigators test for the presence of male cells in women and estimate the number of those cells by measuring the amount of male DNA in blood or tissue samples from the women.)

How could transferred cells survive for so long? Most cells live for a limited time and then die. An exception is stem cells, which can divide indefinitely and give rise to a panoply of specialized cell types, such as ones constituting the immune system or the tissue of an organ. The discovery of long-term microchimerism implied that some of the original émigrés were stem cells or were related descendants. Experiments later supported this assumption. I sometimes think of the transferred stem cells or stemlike cells as seeds sprinkled through the body that ultimately take root and become part of the landscape.

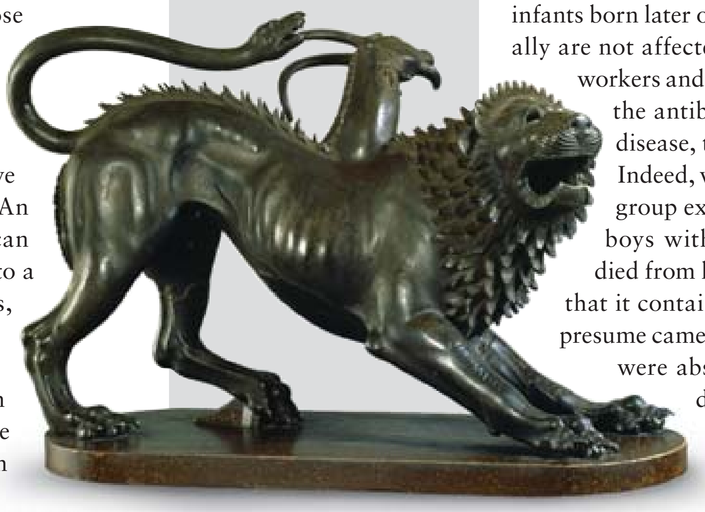
Microchimerism is now drawing intense scrutiny from medical researchers.

My Mother, Myself

The presence of a mother's cells in her offspring—termed maternal microchimerism—is probably a double-edged sword, harmful in some cases but helpful in others. On the negative side, maternal cells may contribute to diseases typically classified as autoimmune, meaning that the immune system unleashes its fire against the body's own tissues. Cells derived from the mother appear to play a part, for instance, in juvenile dermatomyositis, an autoimmune disorder that affects primarily the skin and muscles. Research reported in 2004 by Ann M. Reed of the Mayo Clinic showed that maternal immune cells isolated from the blood of patients reacted to other cells from those same patients. Reed and her co-workers suggest, therefore, that the disease may arise when transferred maternal immune cells take swipes at a child's tissues.

Maternal microchimerism also seems to contribute, albeit in a different way, to neonatal lupus syndrome, believed to arise in part from the destructive activity of certain antibodies that travel from the mother's circulation into her developing baby's. These antibodies apparently home in on fetal tissue and thereby place the newborn at risk for a variety of problems, the most serious of which is a life-threatening inflammation in the heart.

Even though the mothers of affected infants have the disease-causing antibody in their circulation, they themselves are often healthy, and infants born later on to the same woman generally are not affected. That pattern led my co-workers and me to suspect that although the antibodies are important in the disease, they are not the whole story. Indeed, when Anne M. Stevens in my group examined cardiac tissue from boys with neonatal lupus who had died from heart failure, she discovered that it contained female cells, which we presume came from the mother. Such cells were absent or rare in fetuses that died from other causes. More than 80 percent of these maternal cells produced



CHIMERA in mythology combines parts of different animals—a lion, a goat and a snake. A person who harbors the cells of another person is said to be microchimeric because relatively few cells are involved.

BRIDGEMAN ART LIBRARY/GETTY IMAGES

proteins indicating that they were not circulating blood cells but were constituents of heart muscle.

These observations, reported in 2003, implied that the immune attack in neonatal lupus could be targeted to maternally derived cardiac muscle cells in the fetus. The findings also provided evidence for the idea that cells transferred from mother to fetus are stem cells or related cells, because the cells in the affected offspring had apparently differentiated and integrated themselves into the heart. Further, the results add to other findings indicating that some diseases considered to be autoimmune might instead occur when the host immune system reacts badly, not to native tissues but to acquired cells that have made a home in those tissues.

Other work reveals, however, that in some cases, differentiation and integration might not invite immune attack; instead cells integrated into tissues could help repair damaged organs. In 2002 my co-workers and I began to investigate whether maternal microchimerism plays a role in type 1 (insulin-dependent) diabetes. This autoimmune disorder, which strikes primarily children and young adults, erases beta cells (the insulin producers) from the pancreas. We hypothesized that during pregnancy, maternal cells could embed themselves in the fetal pancreas, differentiate into beta cells and, later, become the target of immune attack.

We were only half right. We did find maternal microchimerism more often, and in greater amounts, in the blood of type 1 diabetics than in their unaffected siblings or in unrelated healthy individuals. And we found maternal insulin-producing cells in the pancreas of a diabetic obtained from autopsy. But then we were in for a surprise: we also discovered maternal insulin-producing cells in pancreases from nondiabetics, and we saw no evidence that such cells serve as targets of the immune barrage in diabetics. Instead our results support the conclusion that the maternal cells in the pancreases of diabetics try to regenerate the diseased organ. This finding, published last year, suggests that microchimerism might one day be exploited for therapeutic benefit—if a way could be found to induce the nonnative cells to multiply and differentiate to restore damaged tissues.

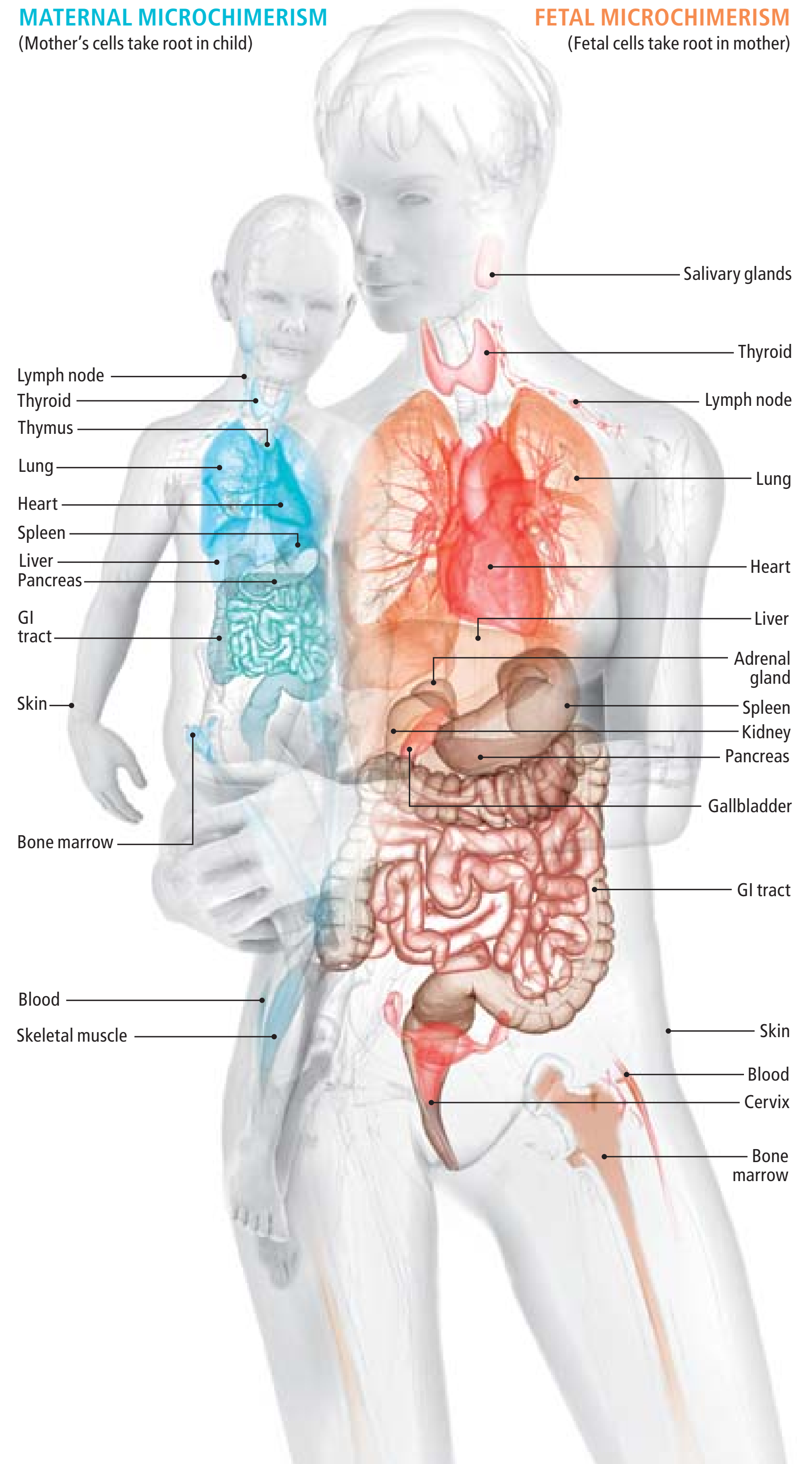
Mixed Blessings from Baby

Like maternal microchimerism, fetal microchimerism—the presence of fetal cells in the mother—appears to be something of a Jekyll-and-

[FINDINGS]

WHERE THE CELLS SETTLE

Microchimerism has been found in many human tissues, including those listed below. It can be detected by looking for female cells in a male (for maternal microchimerism) or male cells in a female (for fetal microchimerism). It can also be noted by analyzing DNA. The presence of Y chromosomes in a woman, for example, signifies that she has acquired cells from a male, most likely from a son during pregnancy.



Hyde phenomenon. I uncovered the unwelcome side in the mid-1990s. Even before my team discovered long-lasting maternal microchimerism in healthy individuals, I was struck by an observation made by Jeff Hall of CellPro, a biotechnology firm, then in Seattle, who was working in prenatal diagnosis. I learned in a phone call one evening in 1994 that a technician in his laboratory had been found to have fetal cells in her blood a full year after the birth of her son. The

[EFFECTS]

DISEASE LINKS

Microchimerism is more common or more pronounced in people with certain disorders (such as those listed below) than in healthy individuals. Sometimes the transferred cells seem to contribute to illness; other times they may combat disease or result from it. For instance, maternal cells have been proposed to attack tissue in those with juvenile dermatomyositis, to be the targets of attack in neonatal lupus and to be trying to come to the rescue in type 1 diabetes. Often the cells' activity is unclear. More research is needed to clarify their roles in specific diseases.

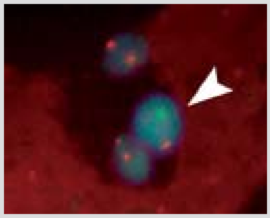
Mother-to-child transfer has been found in:

- **Biliary atresia** (fetal liver disorder)
- **Juvenile dermatomyositis** (immune attack on skin and muscle)
- **Neonatal lupus** (immune attack on various tissues in fetus)
- **Scleroderma** (immune attack that thickens skin and can damage other tissues)
- **Type 1 (insulin-dependent) diabetes** (immune attack on pancreas)
- **Pityriasis lichenoides** (inflammatory skin condition)

Fetus-to-mother transfer has been found in:

- **Breast cancer**
- **Cervical cancer**
- **Multiple sclerosis** (immune attack on neurons of central nervous system)
- **Preeclampsia** (pregnancy-induced hypertensive disorder)
- **Polymorphic eruption of pregnancy** (inflammatory skin condition)
- **Rheumatoid arthritis** (immune attack on joints)
- **Scleroderma**
- **Systemic lupus erythematosus** (immune attack on multiple organs)
- **Thyroid diseases** (Hashimoto's, Graves' and other diseases)

MALE CELL in the liver of a woman is evidence of fetus-to-mother cell transfer. The cell was identified by the one Y chromosome (*green dot*) and one X (*red dot*) in the cell's nucleus (*blue*). The woman's own cells contain two Xs.



Like maternal microchimerism, fetal microchimerism appears to be something of a Jekyll-and-Hyde phenomenon.

conversation caused me to wonder what the consequences of indefinitely harboring cells from one's child might be. And these thoughts led me to ask whether disorders usually viewed as autoimmune might at times involve an interaction between a mother's own cells and those acquired from her fetus.

The idea was too exciting to keep to myself, and in a 1996 hypothesis paper I laid out a constellation of observations derived from very different areas of medicine that led me to question the traditional picture of autoimmune diseases. First, most such disorders affect more females than males and usually strike women in their 40s, 50s and 60s—after many have had pregnancies and often after the time when cyclical hormonal fluctuations might be to blame. If long-lasting cells derived from a fetus have a role to play, one would expect to see such diseases most often in women and in those who have passed their child-bearing years.

A second line of thinking came from the field of transplantation. Transplant surgeons generally attempt to genetically "match" donors and recipients; that is, they try to make sure that certain molecules—called human leukocyte antigens, or HLAs—on the surface of a donor's cells are very similar or identical to those of the recipient. If a donor's HLAs differ significantly, the recipient's immune system will reject the graft, destroying it as if it were a disease-causing agent. Conversely, if cells that come from a donor who is not perfectly matched manage to survive, the transplant can trigger a condition called graft-versus-host disease. In this situation, immune cells in the donated organ attack the recipient's tissue. The reaction causes hardening of the skin, destruction of the gut lining and eventually damage to the lungs.

This constellation of symptoms looks much like what happens to patients with a disease called scleroderma, which is considered to be autoimmune. The similarity suggested to me that fetal cells in the mother might be integral to the process that leads to scleroderma in women. So I proposed to Bianchi that our labs collaborate on investigating that idea. We decided to focus on mothers of males because it is relatively easy to demonstrate the existence of a few male cells within a sea of female cells: we could take blood or tissue samples from women with scleroderma and from healthy women and search for Y chromosome DNA.

In our study, the first to look at microchimerism in an autoimmune disease, we found evi-

ANNE M. STEVENS *Fred Hutchinson Cancer Research Center (liver micrograph)*

dence for the involvement of adopted fetal cells in scleroderma. As a group, patients with the condition had higher levels of fetal microchimerism in their blood than healthy individuals showed. And in other studies, our teams—and, separately, that of Sergio A. Jimenez of Thomas Jefferson University—found fetal microchimerism in the skin and other disease-affected tissues.

We also made another interesting discovery, relating to a certain subset of HLAs called class IIs. HLA IIs on fetal cells in women with scleroderma tend to be more similar to the mother's class IIs than is usual. (Because a fetus inherits half of its genes from the father, up to half of the child's HLA genes, and thus half of its HLA molecules, could differ from the mother's.) Our explanation for this pattern might sound counterintuitive, but we believe that harboring fetal cells whose HLAs differ markedly from a mother's own HLAs is unlikely to be a problem, because the mother's immune system will easily "see" that those cells are foreign and will eliminate them. But cells that look extremely similar in terms of their HLAs might well slip past the mother's first line of immune defense and go unrecognized.

Trouble could occur later on in several ways. If, for example, something causes the mother's immune system to wake up to the interloper's presence, an attempt to then eliminate the cells could cause collateral damage to the mother's own tissues and might even trigger an autoimmune attack. Or perhaps the masqueraders could interfere with the delicate checks and balances that are part of the mother's normal immune system.

Because this area of research is very new, no one knows yet why fetal cells that a mother's immune system has lived with since pregnancy would suddenly be perceived as undesirable aliens decades later, nor how a mother's body comes to tolerate the interlopers in the first place. These intriguing questions will be addressed in the next phase of studies.

Pregnancy Brings Relief

As is true of maternal microchimerism, the fetal type may have good as well as bad effects. In theory, what ways might it be beneficial? In theory, immune cells obtained from a baby could react strongly to disease-causing organisms that the mother's immune system handles poorly; in that situation, the fetal cells might help shore up the mother's immune response. They might also

[THE AUTHOR]

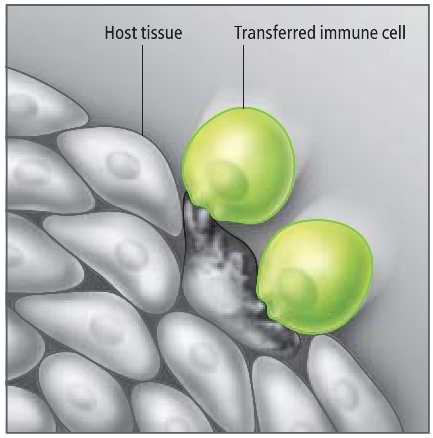
J. Lee Nelson is a member of the Fred Hutchinson Cancer Research Center and a professor of medicine at the University of Washington, both in Seattle. She has been studying the role that microchimerism plays in the initiation and remission of autoimmune diseases since 1986, the year she joined the Hutchinson center. She is also investigating microchimerism's involvement in transplantation, cancer and reproduction. Nelson earned her undergraduate degree from Stanford University and her medical degree from the University of California, Davis, and went on to train in rheumatology at U.W.

[MECHANISMS]

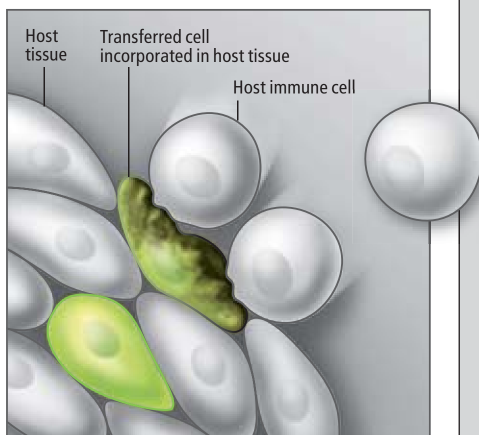
HELP OR HURT?

These are some of the effects that have been posited for cells transferred from one individual to another:

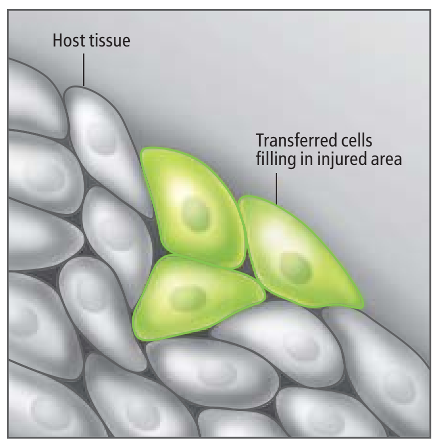
HARMFUL: Transferred immune cells attack host tissue



HARMFUL: Host immune cells attack transferred cells in tissue



PROTECTIVE: Transferred cells attempt to regenerate host tissue that has been damaged



DEAN FORBES *Fred Hutchinson Cancer Research Center (Nelson)*; JEN CHRISTIANSEN *(illustration)*

repair some tissues. And although transfer of fetal cells to the mother might contribute to certain autoimmune diseases, we have some indirect evidence that it can actually benefit women afflicted by at least one autoimmune condition: rheumatoid arthritis, which is marked by chronic, often painful joint inflammation.

Seventy years ago American Nobelist Philip S. Hench observed that rheumatoid arthritis often improves—and sometimes vanishes entirely—during pregnancy and then returns within a few months after delivery. At first doctors invoked hormones, particularly cortisol, which doubles or triples in concentration during pregnancy. But hormones cannot fully account for the phenomenon, because some women with low cortisol enjoy a remission, whereas others with high cortisol do not.

Because pregnancy challenges the immune system (the child is, after all, genetically half-foreign), my colleagues and I sought an immunological explanation for the remission and later reemergence of the disorder. We had discovered in 1993 that the amelioration of rheumatoid arthritis during pregnancy was more likely to occur when the child's set of HLA IIs differed greatly from the mother's. This finding suggested that a disparity in class II HLAs between mother and child could somehow account for the improvement during pregnancy. Later, we found that higher levels of fetal microchimerism in the mother's blood correlated with greater

MICROCHIMERISM FAQs

Is everyone microchimeric?
Each of us probably harbors some maternally derived cells. When my co-workers and I took a single blood draw from healthy adults and tested the equivalent of about 100,000 cells, we found maternal microchimerism in about 20 percent of subjects. But that is a minuscule portion of blood and does not take into account cells that could be in tissues—something that is possible, but challenging, to examine in humans.

How many cells in the body come from our mothers—or our children?
In the circulation maternal or fetal microchimerism is minimal. Calculations based on measuring DNA in healthy individuals indicate that generally fewer than one in 10^5 to 10^6 cells are foreign. But we know that counts can be much higher in tissues than in the circulation. In one study, we were able to obtain a variety of tissue samples from a woman who died of scleroderma. In her case, the numbers varied by organ and cell source. For example, although the DNA measures indicated she harbored about 190 maternal cells and 105 fetal cells for every million of her own cells in a lymph node, in her lungs she had about 760 maternal cells and 3,750 fetal cells per million of her cells.

Aside from two-way transmission between mother and fetus, can microchimerism arise from other natural processes?
Exchange of cells is known to occur between twins in utero, an observation first made in cows. And some twins are lost before being detected by an obstetrician, so microchimerism could derive from a "vanished twin." Also, though not yet proved, microchimerism could be acquired from an older sibling: in this case, the older child, while still a fetus, would have passed some cells to the mother, and mom would pass these cells to a second child during a later pregnancy. Whether microchimerism can occur through sexual intercourse is not known. But indirect evidence indicates that maternal cells can pass to an infant during breast-feeding.

Can blood donation and organ transplantation lead to microchimerism?
Yes. When caused by medical interventions, the phenomenon is termed iatrogenic microchimerism. Donated blood is usually irradiated before it is given to a recipient, which should prevent engraftment. Studies of trauma patients have shown, however, that some who receive multiple unirradiated transfusions retain donor cells years later. Organ recipients likewise may collect and retain cells from the donor, and of course hematopoietic cell (bone marrow) recipients become chimeric.

If alien cells are lodging and living in tissues, why is it that they do not take over a tissue entirely?
This is another open question. It would be a biological disaster if microchimerism were allowed to run rampant. Although this issue has not yet been specifically investigated, researchers feel sure that HLA molecules—the molecules that transplant surgeons generally aim to match in donors and recipients—play a major role in keeping the cells' proliferation in check.

Adopted cells bear HLA molecules that differ from the host's, so why does the immune system fail to recognize and eliminate all such cells?
Perhaps the cells somehow mask their HLA molecules. Or they may "teach" the host's immune system to tolerate them in spite of the differences. But these are speculations. Insight into this question could also shed light on why fetuses, which differ genetically from their mothers, are not eliminated by the mother's body. Interestingly, data suggest that too much HLA sharing during pregnancy is actually bad; fetuses that are miscarried often have more HLAs just like the mother's than do babies that go to term. Nobody knows why that is, although the phenomenon makes evolutionary sense: HLA variance would promote genetic diversity in a population. Such diversity is advantageous because it increases the likelihood that at least some members of the group will have traits enabling them to survive a sudden change in conditions. *—J.L.N.*

BARBARA PENOYAR *Getty Images*

WHAT'S NEXT?

Beyond continuing to investigate immune-mediated diseases, my colleagues and I are beginning to explore the roles (both good and bad) that microchimerism might play in cancer, reproduction and neurobiology. Some of our questions are:

- Preliminary data suggest that persisting fetal cells could contribute to the decrease in breast cancer risk enjoyed by women who have given birth. But what might they do, exactly, to help?
- It seems reasonable to expect that the maternal cells we harbor—which are, of course, older than we are—could be prone to becoming malignant. If they are not, uncovering the mechanisms that guard against such adversity could suggest new ways to prevent cancer.
- Human reproduction has a high failure rate, with frequent miscarriages. Do the cells that adult women harbor from their own mothers influence the fate of their pregnancies? In other words, when it comes to grandchildren does the maternal grandmother have an extra input?
- Finally, can cells acquired from a mother or a fetus defy the blood-brain barrier and work their way into the brain and spinal cord? If so, do maternal cells influence brain development?

—*J.L.N.*

dampening of arthritis symptoms during pregnancy, and plummeting levels correlated with the characteristic postpartum arthritis flare. We do not yet know why more fetal microchimerism or greater HLA II disparity would cause more pronounced improvement of rheumatoid arthritis in pregnant women.

So far investigators have detected fetal microchimerism in such organs as the thyroid, intestines and liver of mothers with a variety of diseases. Some of the cells showed characteristics of the tissues in which they resided. Fetal microchimerism has also been confirmed in circulating immune cells of mothers. Whether these fetal cells are helpful or hurtful may vary in different people or circumstances.

A New View of "Self"

Overall, then, it appears that microchimerism can affect the body in several ways. For instance, transferred immune cells could mount an attack on body tissues, as may occur in juvenile dermatomyositis. Or adopted cells that differentiate into body tissues could elicit attack by the host's immune system, as we believe happens in scleroderma and neonatal lupus. Another possibility is that stowaway cells could be deployed as a relief team, traveling to body tissues that have suffered damage to help with regeneration and restoration of function, as appears to be the case in type 1 diabetes.

Each scenario brings forth the possibility of new therapeutic strategies to consider. If acquired cells are attackers, they could be selectively pinpointed for removal or inhibition. If they are targets of attack, strategies that induce the immune system to tolerate them could be developed. And if they can help regenerate damaged tissues, they might be stimulated to ease diseases marked by tissue destruction.

Although only women are subject to fetal microchimerism, anyone could harbor cells from the mother, including men, children and women who have never been pregnant. Because maternal microchimerism becomes established during development (when the fetus's immune system is forming) and fetal microchimerism occurs when the mother's immune system is mature, the contribution of the two processes to the "self" may differ—just as immigrants who arrive as a nation is being formed may assimilate differently than those who arrive later. We do not yet know very much about those differences. And we understand very little about another intriguing frontier: whether women face unique consequences from harboring cells across generations, both from their own mothers and from one or more of their children.

The discovery that a mother's cells can turn up in her adult progeny and that fetal cells can occur in women who were once pregnant heralds the emergence of microchimerism as an important new theme in biology. The work also challenges the traditional view of self in immunology. Our findings and those of others in this new field support a redefinition that embraces the naturally acquired microchimerism that is probably always with us—from the earliest moments of life well into our adulthood. Also thought-provoking are recent reports of maternal and fetal microchimerism in the brains of mice. These discoveries raise a host of fascinating questions—among them, do maternal cells influence brain development, might fetal microchimerism be harnessed for treating neurodegenerative diseases, and what constitutes our psychological self if our brains are not entirely our own? ■

Anyone could harbor cells from the mother, including men, children and women who have never been pregnant.

➥ MORE TO EXPLORE

Human Natural Chimerism: An Acquired Character or a Vestige of Evolution? Baruch Rinkevich in *Human Immunology,* Vol. 62, No. 6, pages 651–657; June 2001.

Microchimerism: An Investigative Frontier in Autoimmunity and Transplantation. Kristina M. Adams and J. Lee Nelson in *Journal of the American Medical Association,* Vol. 291, No. 9, pages 1127–1131; March 3, 2004.

Maternal Microchimerism in Peripheral Blood in Type 1 Diabetes and Pancreatic Islet β Cell Microchimerism. J. Lee Nelson et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 104, No. 5, pages 1637–1642; January 30, 2007.

Graft and Host, Together Forever. Marguerite Holloway in *Scientific American,* Vol. 296, No. 2, pages 32–33; February 2007.

Building a Future ON SCIENCE

Brazilian neuroscientist Miguel A. L. Nicolelis taps into the chatter of neural populations to drive robotic prosthetics. Now he hopes to tap the potential of his country's population by building them a network of science cities > > > BY CHRISTINE SOARES

KEY CONCEPTS

- A neuroscientist's plan to establish top-quality scientific institutes across Brazil is also a social experiment in distributing the intellectual and economic fruits of science.
- Global networking, heterogeneous funding and fortunate political timing have allowed the project to progress rapidly.
- The expatriate scientists who originated the plan hoped to help shape a competitive nation whose future citizens can excel without having to emigrate.

—The Editors

In a tiny, darkened room on the Duke University campus, Miguel Nicolelis looks on approvingly while a pair of students monitors data streaming across computer screens. The brightly colored dashes and spikes reflect the real-time brain activity of a rhesus macaque named Clementine, who is walking at a leisurely pace on a little treadmill in the next room. Staticky pops coming from a speaker on a back wall are the amplified sound of one of her neurons firing. "This is the most beautiful music you can hear from the brain," Nicolelis declares with a smile.

The run-through is preparation for the next big demonstration of work toward mind-controlled human prosthetics that first garnered worldwide headlines for Nicolelis and his team in 2003. Back then, the group showed that they could listen in on brain signals generated by a monkey using a joystick to play a video game and translate that biological code into commands for a mechanical arm to perform the same motions. Now the group intends to make robotic legs walk under commands from the motor cortex of a monkey strolling along like Clementine. This time the scientists also want to feed sensor data from the robot feet into the monkey's brain, so she can "feel" the mechanical legs' strides as though they were her own. To raise the stakes still further, the monkey will be at Duke in North Carolina, but the robotic legs will be half a world away at the Advanced Telecommunications Research Institute International in Kyoto, Japan.

The complexity of the experiment presents potential obstacles, Nicolelis admits, but satellite transmission delay of the signals traveling to and from Japan is no longer among them. One of the young men in the room, Ian Peikon, found a way to reduce the delay to a negligible 120 milliseconds. "And he's an *undergraduate,*" Nicolelis adds, delighting in the opportunity to illustrate a favorite point—that you don't need a Ph.D. to participate meaningfully in science. The allusion is to a larger personal philosophy that has been driving the 46-year-old neuroscientist's pursuit over the past five years of a very different kind of ambition, perhaps on a par with uploading sensations to the human brain.

Convinced that science is a key capable of unlocking human potential well beyond the rigid hierarchies of academia—and outside the traditional scientific bastions of North America and Europe—his other big project has been nothing less than a quest to transform the way research is carried out in his native Brazil. In the process, he believes, science can also leverage economic and social transformation throughout the country.

The heart of Nicolelis's vision is a string of "science cities" built across Brazil's poorest re-

SCIENCE IN A NOVEL SETTING: The International Institute of Neuroscience of Natal (IINN) research facility in the city of Natal; IINN scientific director Sidarta Ribeiro observes a rodent's brain activity (*top row*). Students build electronics in IINN's Macaíba school; residents of the Natal area (*middle row*). Entrance to the IINN health clinic in Macaíba; neuroscientist Miguel A. L. Nicolelis at the IINN research building entrance in Macaíba (*bottom row*).

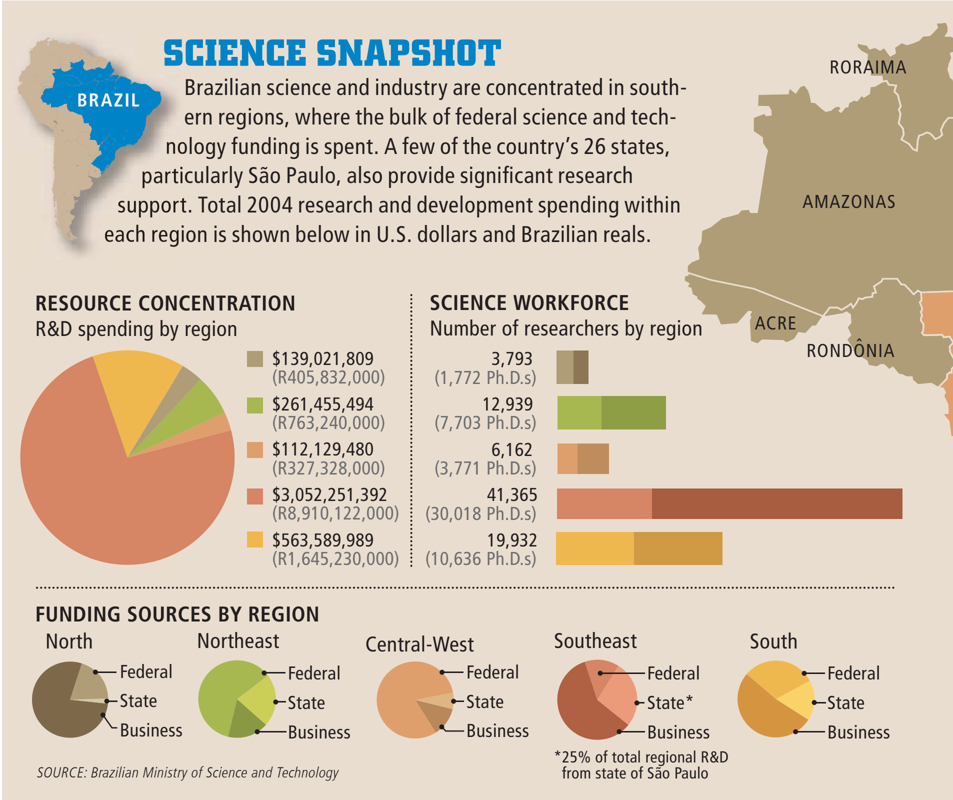
ALL PHOTOGRAPHS BY CRISTOBAL CORRAL VEGA EXCEPT FOR BOTTOM LEFT BY KOICHI SAMESHIMA (*IINN health clinic*)


AASDAP
CENTRO DE ESTUDO E PESQUISA
PROF. CÉSAR TIMO-IARIA
AASDAP


NSTITUTO INTERNACIONAL DE NEUROCIÊNCIAS DE

gions, each centered on a world-class research institute specializing in a different area of science or technology. A web of education and social programs would intimately involve surrounding communities with each institution while improving local infrastructure and quality of life. And the presence of these knowledge-based oases would spark a Silicon Valley–style clustering of commercial scientific enterprise around them, jump-starting regional development.

Nicolelis is used to initial skepticism, even from peers, elicited by the grandeur of the scenario. "Up until a few months ago Brazilian scientists were the biggest doubters of all," he says. Now many observers in Brazil and abroad acknowledge that the momentum his plan has attained in a short time suggests Nicolelis may be on to something.



An Idea Becomes Concrete

By last August the nonprofit foundation that Nicolelis and his partners formed in 2003 to build a proof-of-concept neuroscience institute in northeastern Brazil had raised $25 million, much of it in a large endowment from the widow of billionaire Edmond Safra. On a hilly 100-hectare site in the coastal farming town of Macaíba, three core elements of a "campus of the brain" were also complete. The bright white structures include a 25-lab research building, a free clinic specializing in maternal and child health, and a school that will offer twice-weekly science and art classes to 400 local children, aged 11 to 15, in the first quarter of 2008.

In the larger port city of Natal, 20 kilometers away, another science school has been up and running since last February with about 600 students, along with a suite of labs equipped for Nicolelis's Parkinson's disease research using transgenic mice. A third neuroscience lab run by Nicolelis's group, established at the Sírio-Libanês Hospital in the southern city of São Paulo in exchange for the hospital's sponsorship of the Macaíba clinic, is focused on clinical application of the prosthetics research.

The Macaíba site itself was donated by the state government of Rio Grande do Norte and still lacks a paved access road, but the foundation already has plans for a 5,000-student school, additional lab space, a larger health center, a sports facility and an ecological park to complete what will be the main campus of the International Institute of Neuroscience of Natal (IINN). The Brazilian federal government pledged $25 million toward finishing the complex after President Luiz Inácio Lula da Silva visited the campus in August with his chief of staff and minister of education in tow. Nicolelis had given what he calls "the most important PowerPoint talk of my career" to the president, who is universally known as "Lula," a few weeks earlier.

Back in his spacious office overlooking the leafy Duke campus, Nicolelis recalls that first encounter as feeling slightly surreal. "You know I give lectures all over, but all of a sudden you're talking to the guy who can actually change a lot

LAND IN MACAÍBA donated for the "campus of the brain" sweetened a bid by the state and the Federal University of Rio Grande do Norte to host the AASDAP neuroscience institute in the Natal area.

MIGUEL A. L. NICOLELIS

JEN CHRISTIANSEN

of stuff. And the cool thing is we were talking about science—not talking about building a bridge or a road, we were talking about how to massively educate kids in a country like ours using science as a driving force." After Lula's visit, Nicolelis's group began discussions with Brazil's minister of education about creating a science curriculum for 354 new national technical high schools. "If this works, we'll be up to one million students in two years," Nicolelis says excitedly.

The social components of Nicolelis's plans that are taking shape alongside the scientific facilities are absolutely integral to the institute's purpose in his view. "What we took [to Natal] is not only the idea of doing science at an international level, as we do here [at Duke], but the idea that we let that become part of a school, of a women's clinic, that we merge a scientific enterprise with society." He is keen for scientific research at the IINN to focus on how the brain learns, for example, so that new insights can be incorporated into teaching methods in the schools. Given the importance of early brain development, the clinic will also offer a human milk bank for new mothers who cannot produce their own and will fill an unmet need in the region for neuropediatric treatment. "So it's a huge experiment that links neuroscience with education and health services," he explains.

The plan has continued to evolve ever since it was conceived with two other Brazilian scientists at Duke as a way of raising the caliber of science in Brazil. "It was about repatriating people and reversing the brain drain," Nicolelis says of the idea that he and his postdoctoral fellows Cláudio Mello and Sidarta Ribeiro had in 2002 to establish a world-class neuroscience institute in Brazil. "But we also knew that it had to be a driving force for social change, to demonstrate that, with opportunity, talent anywhere will have a shot." They named the nonprofit they founded to execute their plan the Alberto Santos-Dumont Association for the Support of Research (AASDAP), after the Brazilian who went to Paris in the 1890s to pursue his dream of flying and succeeded.

Meeting Global Standards

In 1989, when Nicolelis and his wife, Laura de Oliveira, left Brazil so that Nicolelis could pursue a neuroscience career, both had medical degrees from the University of São Paulo in Brazil's largest city, and Nicolelis had completed his Ph.D. at the same institution under the guidance of a prominent Lou Gehrig's disease researcher, César Timo-Iaria. But the country had just emerged from two decades of rule by a bureaucratic military regime, research funding was minuscule, and young scientists had few prospects for work. Once in the U.S., Nicolelis also encountered doubts that a Brazilian-trained scientist could amount to much. "What or who of any significance has ever come out of the University of São Paulo?" he says he was asked repeatedly in job interviews.

Starting out at Philadelphia's Hahnemann University, Nicolelis soon became a pioneer in techniques for eavesdropping on hundreds of neurons at once in attempts to decode the fundamental language of the brain. Widely recognized today as one of the world's leading neuroscientists, he credits his own professional success with fueling his conviction that promising young scientists should not have to leave Brazil to realize their full potential.

In the time that he has been away, conditions for Brazilian scientists have improved, although the nation's 2006 public and industry spending on research and development of $14.5 billion is still considerably less than the amount invested by many of the other emerging economies with which Brazil is often compared [*see sidebar on next page*]. Lula has endorsed science and technology as avenues for Brazil's development and recently announced a $23-billion

LEFT BEHIND

Natal is the capital of Rio Grande do Norte, an underdeveloped state that contributes less than 1% of gross domestic product (GDP).

POPULATION

NATAL: 789,896
(metropolitan area: 2.7 million)

BRAZIL: 186.8 million

INFANT MORTALITY
(per 1,000 births)

NATAL: 36.1

BRAZIL: 25.1

ILLITERACY ABOVE AGE 15

NATAL: 21.5%

BRAZIL: 11%

LIFE EXPECTANCY

NATAL: 70.1

SÃO PAULO: 73.9

STATE CONTRIBUTION TO NATIONAL GDP

RIO GRANDE DO NORTE: 0.9%

SÃO PAULO: 30.9%

SOURCE: Brazilian Institute of Geography and Statistics

FAST FACTS

The AASDAP logo incorporates the *14-bis,* the airplane flown by aviation pioneer Alberto Santos-Dumont in 1906 near Paris to win two European prizes for the first flights of a powered, heavier-than-air craft. The Southern Cross constellation reflects AASDAP's goal of enabling Brazilians to "fly" in their own land.

GLOBAL GOAL

Nations with transitional economies similar to Brazil's are pinning development hopes on science and technology, some investing a larger proportion of national resources.

GROSS EXPENDITURE ON R&D, 2004
(in billions of U.S. dollars/ as a percentage of GDP)

BRAZIL: $13.5/0.91%

CHINA: $95.5/1.23%

INDIA: $23.7/0.69%

SINGAPORE: $2.6/2.23%

SOUTH KOREA: $28.3/2.85%

TAIWAN: $15/2.38%

SOURCE: Organization for Economic Co-operation and Development

boost to the research budget over the next three years.

The president's embrace of science is undoubtedly encouraged by some recent high-profile demonstrations of the fruits of research spending, notes physicist Sergio Mascarenhas de Oliveira, director of the Institute for Advanced Studies of São Carlos, part of the University of São Paulo. Mascarenhas praises the national agricultural research corporation, Embrapa, in particular for its leadership in developing ethanol and other biofuels as well as staking out tropical agricultural biotechnology as an area where the country can establish expertise. In 2000 a consortium of some 30 Brazilian laboratories produced a genome sequence of *Xylella fastidiosa*, an important citrus crop parasite, and several other projects to sequence crop plants, such as sugarcane, are under way. "Embrapa is in the process of changing our [nation's] export commodity from raw materials to applied science," Mascarenhas says. "What Brazil still doesn't know how to do is to transform research from the university into products and venture capital," he adds, blaming the weakness in part on an ivory-tower culture in Brazil's largely university-based research community.

Not surprisingly, some of those scientists were dubious of the Natal project, Mascarenhas recalls. Nicolelis's concept of a network of independent research centers, inspired by Germany's prestigious Max Planck institutes, is unusual for Brazil. The AASDAP motto, "The Future of Science in Brazil Starts Here," definitely did not help, Mascarenhas notes. And if the approach alienated some Brazilian scientists, the decision to locate the first institute in the impoverished hinterland of Natal also mystified many of them. Nicolelis thinks that the institute's social and economic influence will be most visible in the communities around Natal and Macaíba, and that the region is exactly where such transformation is most needed.

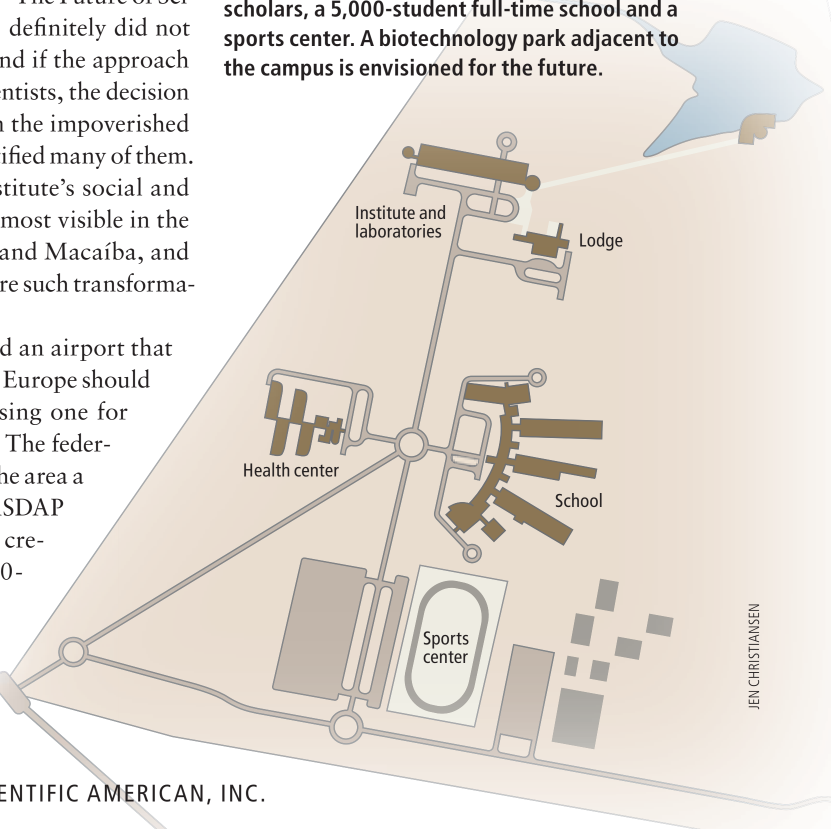
Moreover, the seaport and an airport that receives nonstop flights from Europe should make the location a promising one for commercial science, he says. The federal government has declared the area a free-enterprise zone, and AASDAP staff is now negotiating the creation of a 1,000- to 2,000-hectare biotech park, which Nicolelis hopes will attract businesses focused on products for export, such as pharmaceuticals and biofuels. Meanwhile he is in talks with several other states interested in hosting the next three institutes, whose specialty areas will likely be bioenergy, microelectronics and environmental science.

The New Science City

As a means to promote regional economic development, the strategy of clustering high-tech businesses around major research institutions in the hope of spurring innovation has never been more popular. Local and national governments, especially across Asia, are spending billions to build such science parks and "cities" as they peg their development goals to science.

In 2006 China declared its plan to construct 30 new science cities and to raise its annual research spending to more than $100 billion by 2020. At that point, the government expects 60 percent of the country's economic growth to be based on science and technology. India, where a small number of elite universities have become hubs for technology clusters, as in Bangalore, is also betting on a continued tech boom. Although their approaches differ, what many of these nations have in common is an overt goal of luring a diaspora of scientists trained in the West to bring their expertise back home, notes Marina Gorbis,

PLANS for the as yet unbuilt components of the campus of the brain in Macaíba include a larger health center, headquarters and laboratory space for the IINN, lodging for visiting students and scholars, a 5,000-student full-time school and a sports center. A biotechnology park adjacent to the campus is envisioned for the future.



A Natal slide show and an essay by Miguel Nicolelis, "Building the Knowledge Archipelago," are at **www.SciAm.com/ontheweb**

ELECTRONICS CLASS is among the twice-weekly sessions offered at the IINN Macaíba school in partnership with regular local schools. Classes in chemistry, physics, biology, robotics, computers and art are also part of the program at the IINN Macaíba and Natal schools, which together have 1,000 students.

CRISTOBAL CORRAL VEGA

executive director of the Institute for the Future (IFTF), a think tank in Palo Alto, Calif. "The example most often cited is Taiwan," she says, "where the whole semiconductor industry is based on expats who stayed here in the Silicon Valley for 20 years, then went back. We're seeing it happen in China, too: professors going back and establishing their labs, and they're bringing their students and contacts and becoming magnets." Nicolelis is probably one of a handful of Brazilian scientists with the stature to play the same role in his country, Gorbis adds.

She and IFTF research director Alex Soojung-Kim Pang led a yearlong project to produce the "Delta Scan," a broad analysis and forecast of science and technology trends commissioned by the British government. In it, they flagged Brazil as a possible world scientific leader by 2025 and the Natal initiative as an example of the direction the country will need to take to get there. The potential for transdisciplinary research within and among AASDAP institutes is an important advantage in Gorbis's view. And Nicolelis's own emphasis on collaboration between his Duke lab, the IINN sites and international partners embodies a globally networked style of working that Delta Scan authors considered essential to Brazil's ability to produce world-class research. Pang also sees the IINN's launch, enabled primarily by international donations at first, as the shape of things to come elsewhere. "The other interesting story," he notes, "is the rise of private capital in supporting these kinds of centers and supporting what we would normally think of as big science projects." The next evolution in science-based development, Pang observes, is a less structured and less government-driven "innovation zone" arising from the joint efforts of entrepreneurs, philanthropists and researchers.

Harvesting Human Potential

Whether the Natal model can help Brazil catch up to the countries pouring many times more resources into science and technology remains to be seen. As the world's fifth largest nation in land area and one exceptionally rich in diverse natural resources, Brazil has long been described as "the country of the future," possessing nearly all the ingredients needed to become an economic powerhouse. Most analysts cite the country's own legal system as being one of the biggest obstacles to Brazil's reaching its full potential.

Bureaucracy, burdensome taxes, and weak enforcement of antitrust and intellectual-property laws are blamed for stifling the population's natural entrepreneurial dynamism. A poor school system and high illiteracy rates are the other major barriers to progress most often named.

In that light, the most unorthodox aspect of the Natal project could be its greatest strength. Nothing like the educational effort on the scale envisioned by Nicolelis has ever been tied to a science-city initiative. "A few give it lip service," Pang says, "but even then they're mainly talking about university-level education."

In Nicolelis's view, reaching children well before college age is crucial. He believes that science education strengthens critical thinking skills in general, and he plans to use improvements in the children's regular school performance as a benchmark for the effectiveness of the supplementary classes at institute science schools. If some of the kids become interested in pursuing science and technology careers, they will find plenty of opportunities in the knowledge economy. "Ninety-nine percent of scientific work doesn't require a Ph.D.," he insists.

But he is careful to clarify that he is not trying to create a nation of scientists. "We are trying to create a generation of citizens capable of leading Brazil," Nicolelis explains. "These kids already have the hopes—now what they need is the tools." Whether they want to be doctors, architects, pilots or president, he is confident that the experience of hands-on scientific inquiry can instill a feeling of empowerment that the children will carry into adulthood and use to carry their country into its long-awaited future. ■

➥ MORE TO EXPLORE

Brazil Institute Charts a New Hemisphere for Neuroscience. Marcia L. Triunfol and Jeffrey Mervis in *Science,* Vol. 303, pages 1131–1132; February 20, 2004.

The Scientific Muscle of Brazil's Health Biotechnology. Marcela Ferrer et al. in *Nature Biotechnology,* Vol. 22, supplement, pages DC8–DC12; December 2004.

Dreaming of Glory: A Special Report on Brazil. Supplement to the *Economist.* April 14, 2007.

Delta Scan: The Future of Science and Technology, 2005–2055. Institute for the Future. **http://humanitieslab.stanford.edu/deltascan/Home**

International Institute of Neuroscience of Natal English-language Web site: **www.natalneuro.org.br/_eng/index.asp**

Maverick against the Mendelians

Using standard inheritance theory, scientists have searched for the genes underlying autism with little success. Michael Wigler thinks he knows why—and how the disorder persists over generations BY NIKHIL SWAMINATHAN

Ask Michael Wigler about the genetic basis of autism, and he will tell you that the standard genetic methods of tracing disease-causing mutations in families with multiple affected members are not working. Although most scientists agree that environmental influences play a role in disease onset, autism has a strong genetic component: among identical twins, if one is autistic, there is a 70 percent chance the other will show the disease, a risk factor nearly 10 times that observed in fraternal twins and regular siblings. Yet years of time and bags of money have been spent unsuccessfully looking for genes linked to the condition.

To Wigler, a geneticist at Cold Spring Harbor Laboratory on Long Island, the key to unlocking autism's genetic mystery lies in spontaneous mutations—alterations in the parental germ line that are novel in offspring. Last year he proved that spontaneous events contribute to some cases of autism and then formed a controversial theory for the genetics of the disorder. It suggests, among other things, that females, who develop autism with a quarter of the frequency with which males do, may carry the genetic profile for the illness, which they then pass on to their children.

As Wigler sees it, conventional genetic studies have failed because they have corralled families that have more than one autistic child to search for differences in one base along the genetic code. These differences, which are presumed to affect neural connectivity, can be an addition, a deletion or a substitution of a base and are known as single nucleotide polymorphisms (SNPs). In autism research, uncovering SNPs shared by affected people would enable scientists to determine who would have an elevated risk for acquiring the disease or passing it on.

MICHAEL WIGLER

SPORADIC THOUGHTS: Proposes that spontaneous mutations, in addition to mutations that follow standard Mendelian inheritance patterns, can explain autism's puzzling heredity and perpetuation.

MYSTERY DISORDER: Autism symptoms range from cognitive deficiencies to asocial and obsessive behavior. It afflicts one out of every 150 children born in the U.S.

CASTING A WIDE NET: Believes that his unified theory of autism may also help explain other complex genetic diseases, such as schizophrenia, depression, morbid obesity and diabetes.

BRIAN MARANAN PINEDA

The problem is that research groups have rarely fingered the same places on the same genes: they have implicated regions, or loci, on 20 of the 23 pairs of chromosomes in the genome. "We felt like we reached a dead end with SNPs," says Portia Iversen, the mother of a 15-year-old autistic boy and founder of the advocacy group Cure Autism Now.

"People were really breaking their teeth on this," explains the 60-year-old Wigler. The SNP people "tried to deal with [the problem] by saying, 'These are complex disorders caused by the alignment of the planets'—that there would be four or five loci and that if you got the wrong allele configuration of these four or five loci, you would have the disorder."

Such justifications are unsatisfying to Wigler, who has experienced three decades of success as a geneticist. In 1981 he isolated the superfamily of *RAS* genes, the first suite of cancer genes ever identified. In the 1990s he conceived of a method to sample segments of a genome, allowing for a quick, inexpensive comparison of the DNA. He then employed this gene-chip technique, now known as representational oligonucleotide microarray analysis, to scan for DNA disruptions that may lead to cancer.

In his first foray into autism, Wigler, working primarily with his Cold Spring Harbor colleague Jonathan Sebat, set out to determine what role,

if any, spontaneous mutations called copy number variations may play in the disorder. These mutations affect the number of copies of a gene a person has. Before scientists sequenced the human genome, researchers thought that an individual always had two alleles, or copies of a gene—one inherited from each parent. In 2004 the Cold Spring Harbor team showed that even in healthy individuals, copies of genes could go missing from (or be added to) the genome via large-scale rearrangements of genetic material. (Such rearrangements have for years been known to account for particular manifestations of many disorders, including Huntington's disease.) By focusing on families with only one autistic member, the team showed last March that up to 10 percent of noninherited autism cases could be caused by spontaneous copy number variations. Wigler and Sebat found that the structural events were primarily deletions, leaving individuals with only one copy of a particular gene and leading, in some cases, to a disruption of that gene's function (a condition known as haploinsufficiency).

As a bold follow-up, Wigler published a paper in late July that unveiled a unified genetic theory for autism, which he cobbled together by examining data from families with multiple autistic individuals and incorporating both hereditary as well as spontaneous events. Focusing on families where the first two children were affected, he found that third-born male children have a 50 percent risk of acquiring the disorder, whereas the risk for third-born girls is closer to 20 percent.

From that data point, Wigler developed a simple two-tiered hypothesis: The vast majority of families fall into the low-risk category, in which affected children have a spontaneous mutation, either a copy number variation or a point mutation. On the other hand, high-risk families—which make up 25 percent of all autism cases, according to Wigler's numbers—manifest the disease when an unaffected individual, most likely a female, carries a sporadic mutation and passes it down as a dominant allele. If the offspring happens to be male, Wigler estimates that his chance of developing autism is roughly 50 percent.

GENERATIONAL PUZZLE: Some healthy people may carry autism genes, which could explain the disorder's hereditary patterns.

Deborah Levy, director of the psychology research laboratory at Harvard Medical School's McLean Hospital, calls Wigler's theory "a completely different framework" for looking at the disorder. "Rather than having multiple genes of small effect," she says, "you have a single gene that's accounting for the disorder," although many different genes—up to 100, by Wigler's estimate—can play that role.

Wigler explains that some sporadically altered or deleted genes have high penetrance (conferring high risk), especially for males. These particularly nasty mutations typically disappear within two to three generations, but autism will likely persist as a phenotype because carriers, mostly women, have modifying genes that protect them. Such genes, however, are less likely to shield male descendants. "The rates of autism are really quite high, and it would be a striking thing to say that most of autism is spontaneous mutation," Wigler explains. "It says that we are living with evolution."

Although some autism investigators see Wigler's spontaneous mutation model as a simpler way to view the genetics of the disease, others find it incomplete. According to behavioral scientist David Skuse of University College London, critics note that it does not account for observations of families with an autistic child in which either second- or third-degree relatives are also affected or in which first-degree relatives show mild symptoms of the disorder. And the model fails to explain why girls do not get autism with the same frequency as boys.

Wigler believes that more statistical data might help prove his theory (which he views as a boast). For instance, the girl-boy discrepancy could be explained if the genetic modifiers are sex-specific, an effect that might become apparent if, he says, researchers look at cases in which a normal mother has an autistic daughter. "This is not the kind of theory where you can comfort yourself with it and say the mystery is solved," he says. "It's the kind of theory that gets you out of bed and doing something."

On a Friday afternoon in his office, Wigler chats excitedly about a movie he just received from Netflix. "Have I told you about my first intellectual awakening?" he asks. He is referring to the film *Alexander the Great,* Robert Rossen's 1956 tale of the Macedonian conqueror, which his grandfather took him to see when he was nine years old. In it, Alexander (played by Richard Burton) is confronted with the Gordian knot, a tangle of bark rope that mythology foretold would grant to the one who managed to unravel it the legacy of conquering all of Asia. Rather than grappling with the intractable bulge, Alexander draws his sword and hacks through it.

On recounting the story, Wigler quips: "Sometimes you have a problem, and people don't see the solution—because they're not looking at it directly." But only more data will prove whether his view of autism is truly straight on. ■

A Q&A VERSION *is at* **www.SciAm.com/ontheweb**

MICHAEL MACOR *San Francisco Chronicle/Corbis*

Leap of Faith

By Mark Fischetti

Movie viewers know that an actor cannot swing like a spider from a skyscraper or converse with an animated rabbit, but visual-effects artists make such scenes believable. The technique they exploit is the matte process—commonly called blue screen or green screen for films and chromakey for television.

The process, pioneered in the late 1930s, remained largely unchanged for decades. An actor was filmed onstage in front of a blue or green drape or wall, then a different background scene was filmed. Technicians masked out the drape color, made positive and negative transparencies, physically overlaid the strips and projected them onto fresh film—creating the final composite scene. This "optical printing" exercise was tedious and costly but effective. Another process was later developed for television broadcasting.

A backdrop could be any color—but because red, green and blue correspond to film's three emulsion layers and to a television camera's three color channels, they are easiest to filter. Red is common in skin tones, however, and masking it out complicates skin's appearance, so that color is often avoided.

Only in the mid-1990s did a fully computerized process begin to take over, in which software converts film frames to digital files and allows artists to manipulate them [*see illustration below*]. Moviemakers have rapidly embraced the technique because it is faster, cheaper and more refined. Most feature films today are assembled digitally.

Human editors must still conduct the procedure, however, adjusting shadows, correcting colors and fine-tuning outlines so viewers will not perceive fleeting apparitions or artifacts. "Despite the technology, the process is still an art form; it still requires the human touch," says Chris Cookson, chief technology officer for Warner Bros. Entertainment in Burbank, Calif.

Success at major studios has spawned simpler matte pro-

DID YOU KNOW ...

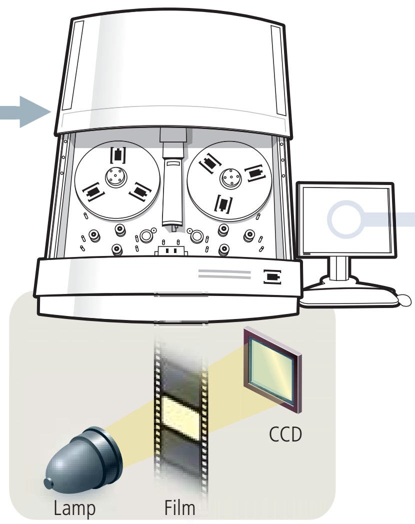
THEN AND NOW: Movie viewers who would like to see how software has improved matting can compare the original *Star Wars: The Empire Strikes Back* (1980) and the 2004 DVD version, which was remastered using more refined techniques; both are included in the 2006 Limited Edition DVD of the film. The HD DVD of the film *300* includes a bonus feature showing how extensive blue screening was done.

WITNESS: Software sometimes has difficulty cleanly matting complex backgrounds with actors who are moving quickly across a blue or green screen. Technicians may paste tennis balls or bright dots in a pattern on the screen to act as reference or "witness" marks that can help editors fine-tune the tracking. The mark color must also be matted out. The aid was used extensively in *Space Jam*, the 1996 basketball romp starring Michael Jordan and Bugs Bunny.

FILM

On a stage with a blue or green screen, a leaping actor is recorded on 35-mm film.

A real-life background is filmed.



A CCD or CRT scanner digitizes each film frame of the actor and stores the data in a computer's hard drive. It does the same for the background scene.

IN THE COMPUTER

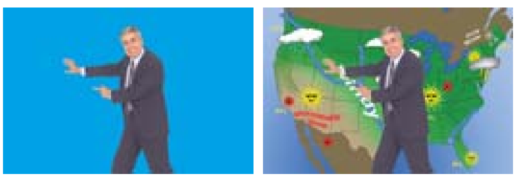
Editing software substitutes white for the blue wavelength.

BLACK 100 *Getty Images* (*jumping figure*); JOSON *Getty Images* (*background shot*); 5W INFOGRAPHICS (*CCD and CRT illustrations*)

grams for home and digital video buffs, such as Final Cut 6 and Avid Xpress, which have improved quickly. The products are "almost like getting a $30,000 editing and special-effects system in a $1,200 software package," says Walter Graff, a director and cinematographer in New York City. Whether an enthusiast has the eye and skill to exploit that package like a professional is another story.

TELEVISION

A camera sends a video feed of a weather announcer to a computer. Chroma-key software subtracts the blue wavelength, defining it as a transparent hole. In its place, the software inserts a second feed of graphics, such as a map. If the weatherperson wears a blue tie of similar wavelength, viewers will see it as a hole. Technicians use the same technique to insert video footage behind a newscaster.

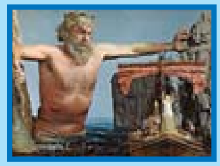


SW PRODUCTION/ BRAND X/CORBIS

BLUE-SCREEN NOTABLES

1940 *Thief of Bagdad*, first use of manual blue-screen technique

1963 *Jason and the Argonauts*, sophisticated combination of live actors and stop-motion animation



1980 *Star Wars: The Empire Strikes Back*, minicomputers automated the blue-screen process

1988 *Who Framed Roger Rabbit*, combined live actors with computer-animated characters

1995 *Under Siege II*, filmed on an entirely green stage, so cameras could shoot different perspectives

2000 *O Brother, Where Art Thou?*, one of the first Hollywood movies produced digitally end to end even though it had few special effects

2006 *300*, new sophistication in mixing live and computer-generated characters and backgrounds

EVERETT COLLECTION (*top*); BUENA VISTA/EVERETT COLLECTION (*middle*); © WARNER BROS./EVERETT COLLECTION (*bottom*)

It then defines the remaining image as black. The software seeks sharp changes in luminance—the black-and-white boundary—to outline the actor.

Software replaces the white background with the new background, recorded in one digital file, or channel.

Software adds the matted color image in a second channel.

A CRT inside a film recorder displays both channels simultaneously and projects them onto new 35-mm film.

The final scene. The process is repeated for each frame of film shot of the actor onstage.

SEND TOPIC IDEAS *to workingknowledge@SciAm.com*

Oil vs. Autos ▪ Science Imitates Art

BY MICHELLE PRESS

➔ ZOOM: THE GLOBAL RACE TO FUEL THE CAR OF THE FUTURE
by Iain Carson and Vijay V. Vaitheeswaran. Twelve, 2007 ($27.99)

The authors, both correspondents for the *Economist,* argue that to protect the environment and lessen our dependence on oil, we must rethink the automobile. Oil is the problem, they say; cars are the solution. They are hugely optimistic about the time frame for the new generation of cars, contending that the revolution is already under way—in Japan, Silicon Valley, India and China—as entrepreneurs work on cars powered by hydrogen, electricity and biofuels. Toyota gets credit for creating a steppingstone to the future car in the Prius. The book reads as if it had been written in haste (far too many playing fields need leveling, and there is a plethora of gurus), but it contains some provocative insights.

➔ OBJECTIVITY
by Lorraine Daston and Peter Galison. Zone Books, 2007 ($38.95)

This book examines the remarkable appearance of scientific objectivity in the 19th century. Daston of the Max Planck Institute for the History of Science in Berlin and Galison of Harvard University unfold this history by exploring scientific atlases (as a result the book has more than 150 intriguing images). The authors uncover three guiding principles in objectivity's trajectory: "truth to nature," an idealized mode of observation (think of early botanical drawings); "mechanical objectivity," which reveals objects without the taint of subjectivity (think of photographs and micrographs); and "trained judgment," in which subjective interpretation gradually returns to scientific representation (think of images of the earth's magnetic field). Not a light read but fascinating.

EXCERPT

➔ PROUST WAS A NEUROSCIENTIST
by Jonah Lehrer. Houghton Mifflin, 2007 ($24)

While he was working as a technician in a neuroscience lab, trying to figure out how the brain stores memories, Lehrer was also reading Proust. He began to notice a surprising convergence. "The novelist had predicted my experiments," he writes. This led him to consider other artists who had anticipated modern scientific findings, among them Cézanne, Stravinsky and Virginia Woolf.

"One of Proust's deep insights was that our senses of smell and taste bear a unique burden of memory. . . .

"Neuroscience now knows that Proust was right. Rachel Herz, a psychologist at Brown, has shown . . . that our senses of smell and taste are uniquely sentimental. This is because smell and taste are the only senses that connect directly to the hippocampus, the center of the brain's long-term memory. Their mark is indelible. All our other senses (sight, touch, and hearing) are first processed by the thalamus, the source of language and the front door to consciousness. As a result, these senses are much less efficient at summoning up our past.

"Proust intuited this anatomy. . . . Just looking at the scalloped cookie brought back nothing. Proust even goes so far as to blame his sense of sight for obscuring his childhood memories in the first place. 'Perhaps because I had so often seen such madeleines without tasting them,' Proust writes, 'their image had disassociated itself from those Combray days.' "

SUSAN MARIE ANDERSON *Foodpix*

NEW AND NOTABLE TAKES ON THE ENVIRONMENT

Among the current spate of books on environmental concerns, several follow the path less traveled, to good effect:

1 Thrillcraft: The Environmental Consequences of Motorized Recreation
edited by George Wuerthner. Chelsea Green Publishing Company, 2007 ($60), 11 ¾ × 13 ¼ inches
Striking large-format color photographs of the lasting damage wrought by Jet Skis, dirt bikes, dune buggies and other "wreckreational" vehicles.

2 Six Degrees: Our Future on a Hotter Planet
by Mark Lynas. National Geographic, 2008 ($26)
Outlines what to expect from a warming world, degree by degree. A one-degree-Celsius rise would destroy most coral; six degrees would eliminate much of humanity.

3 The Great Warming: Climate Change and the Rise and Fall of Civilizations
by Brian Fagan. Bloomsbury Press, 2008 ($26.95)
A history of the Great Warming of half a millennium ago suggests we may be underestimating the power of climate change to disrupt our lives today.

4 Auto Mania: Cars, Consumers, and the Environment
by Tom McCarthy. Yale University Press, 2007 ($32.50)
Environmental problems caused by automobiles were recognized early; addressing them has been another matter.

5 What We Know about Climate Change
by Kerry Emanuel, with an afterword on what to do next by Judith A. Layzer and William R. Moomaw. A Boston Review Book, MIT Press, 2007 ($14.95)
The most unusual thing about this book is its size—at roughly 7,000 words, it is disarmingly small for the punch it delivers.

6 101 Funny Things about Global Warming
by Sidney Harris & Colleagues. Bloomsbury Press, 2008 ($15.95)

*How do the **same fish species** end up in **different lakes** hundreds of miles apart?*

—S. Snyder, Sebring, Fla.

Megan McPhee, an assistant research professor at the University of Montana's Flathead Lake Biological Station, offers this explanation:

There are two general explanations for how a fish species might end up in different lakes separated by great distances.

The first is termed "vicariance" by biogeographers, who study the distribution of organisms. In this case, a species originally occupies a much larger, continuous range. Over long periods, geologic, biological and climatic events cause populations to go extinct in scattered places throughout that range, leaving behind isolated present-day populations. For example, during the late Pliocene and Pleistocene epochs (between two million to 0.5 million years ago), western North America experienced a much wetter climate and giant lakes occupied many basins. When an increasingly arid climate swept into the area, large lakes dried into separate, smaller ones—leaving fish species isolated.

The second explanation is based on dispersal, or movement of individuals away from the population in which they were born. Sometimes these individuals spread into new areas previously unoccupied by members of their species. In fish, where most species require male-female sex to reproduce, a minimum of one of each sex would be needed to colonize a new lake. Whereas the chance of this event happening once is quite small, in time enough opportunities will arise for these rare dispersals to result in the colonization of new lakes.

Over longer periods, dispersal is often facilitated by headwater capture—a river tributary erodes through the divide between two rivers, thus linking them. Although this mechanism is primarily responsible for the transfer of river-dwelling fish, it can also move lake fish between basins if they spend part of their life cycle in rivers.

Finally, humans are responsible for moving fish great distances. In many cases, this dispersal occurs intentionally because people want to fish for a particular species outside its native range. In the late 19th century the U.S. Fish Commission made concerted efforts to introduce carp—as a food fish—into the waters of the western U.S., where they can now be found in lakes and reservoirs throughout the region. Unsanctioned or even accidental transfer occurs when people release aquarium fish or empty out bait buckets into wild habitats. We have learned that nonnative fish (including carp) often prey on or compete with native species, so such practices are now largely discouraged.

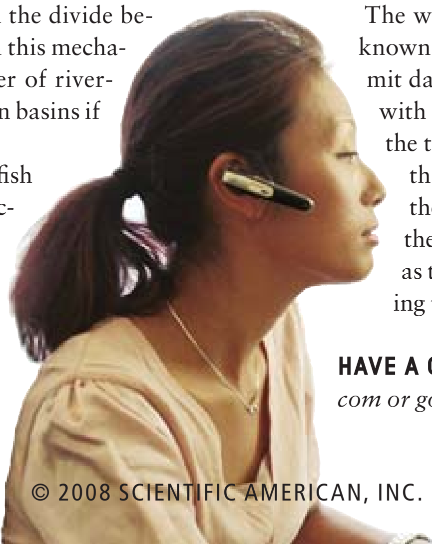
*How does **Bluetooth** work?*

Bluetooth Special Interest Group executive director **Michael Foley** transmits an answer:

Bluetooth is a short-range wireless communications technology that replaces the cables connecting electronic devices. It uses the principles of device "inquiry" and "inquiry scan." Scanning devices listen in on known radio frequencies for devices that are actively inquiring. When the scanner receives an inquiry, it sends a response with the information needed to forge a connection.

A group of devices then forms a so-called piconet, which may contain one master and up to seven active slaves, with additional slaves that are not currently participating in the network. (A given device may be part of more than one piconet, either as a master or as a slave.) In a piconet, the devices are synchronized to a common clock and frequency-hopping pattern, and they share a radio channel. The pattern, which the master device determines algorithmically, helps to combat interference and fading. The basic hopping pattern cycles through the 79 available frequencies, but it may be adapted to exclude those that are used by interfering devices, improving Bluetooth's coexistence with static (nonhopping) systems, such as Wi-Fi networks, that may be in the vicinity of a piconet.

The wireless link is subdivided into time units known as slots. Bluetooth-enabled devices transmit data in so-called packets during these slots, with frequency hopping taking place between the transmission and reception of packets. All this complexity, of course, goes on without the user being aware of anything more than the task he or she is trying to complete, such as talking hands-free on a cell phone or listening to music on wireless headphones. ■



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Do Antibacterial Soaps **Do More Harm** Than Good?

BY COCO BALLANTYNE

Soaps, household cleaners, sponges, and even mattresses and lip glosses now pack bacteria-killing ingredients. Does adding those ingredients make sense?

Traditionally people wash bacteria from their bodies and homes using soap and hot water, alcohol, chlorine bleach or hydrogen peroxide. Soap works by loosening and lifting dirt, oil and microbes from surfaces so that they can be easily rinsed away with water. General cleaners such as alcohol inflict sweeping damage to cells by demolishing key structures, after which the cleaners evaporate. Products containing antibacterial agents, in contrast, leave surface residues, notes Stuart Levy of the Tufts University School of Medicine.

CHRISTOPHER STEVENSON *Getty Images*

Spurring Evolution

This persistence is problematic. When a bacterial population that survives the first hit of an antibacterial agent vies with the lingering chemical, a small subpopulation armed with special defense mechanisms can evolve. This group then multiplies as its weaker relatives perish, and it will withstand attack the next time the chemical is applied. "What doesn't kill you makes you stronger" is the governing maxim here; antibacterial chemicals select for bacteria that can endure their presence.

Resistance to topical chemicals is not the only risk. When bacteria become tolerant to these compounds, they sometimes also become less sensitive to certain antibiotic medicines. This phenomenon, called cross-resistance, has already been demonstrated with triclosan, one of the most common chemicals in antibacterial products.

Genetic mutations can arise in bacteria exposed to triclosan for long periods and endow certain types of bugs with resistance to isoniazid, an antibiotic used for treating tuberculosis, explains Allison Aiello of the University of Michigan School of Public Health. Other mutations can allow microbes to supercharge their efflux pumps—protein machines in the cell membrane that can spit out several types of antibiotics, including ciprofloxacin, used to treat anthrax. These effects have been demonstrated only in the laboratory, not in households and other real-world environments, but Aiello suspects that the few household studies conducted so far might not have been long enough. "The potential is there," she says.

Scientists have further concerns about antibacterial compounds. Both triclosan and its close chemical relative triclocarban are present in 60 percent of U.S. streams and rivers, points out Rolf Halden of the Johns Hopkins Bloomberg School of Public Health.

Both chemicals also end up in the sludge produced by wastewater treatment plants, which is used as fertilizer for crops, thereby opening a potential pathway for contamination of food, Halden says. "The concentrations in agricultural soil are very high," and this abundance, "along with the presence of pathogens from sewage, could be a recipe for breeding antimicrobial resistance" in the environment, he adds.

Triclosan has also been found in human breast milk, though not in concentrations considered dangerous to babies, as well as in human blood plasma. There is no evidence that current concentrations of triclosan in the human body are harmful, but recent studies suggest that it compromises the function of the hormone systems in bullfrogs and rats.

No Benefit

Ultimately, the value of such antibacterial additives is questionable. An expert panel convened by the U.S. Food and Drug Administration determined that there is insufficient evidence for any benefit from consumer products containing them. "What is this stuff doing in households when we have soaps?" asks John Gustafson of New Mexico State University.

Some scientists argue that consumer use of antibacterial products is appropriate in the homes of people with weakened immune systems. In general, however, good hygiene means using regular soaps rather than antibacterial ones, experts say. "The main way to keep from getting sick," Gustafson says, "is to wash your hands three times a day, and don't touch mucous membranes." ■

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

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