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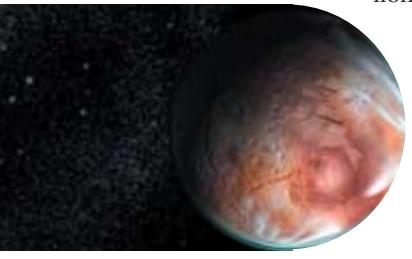
Last Chance for the Last Planet

Scientists joke that it can take longer for a space mission to escape from Washington, D.C., than to cross the solar system: the harshness of outer space is nothing compared with the rigors of securing administrative, presidential and congressional approval. Never has this been truer than for a mission to Pluto. In one form or another, a space probe to the outermost planet—the only major unvisited world in the solar system—has been traveling for more than a decade and still has yet to clear the Beltway. Unless Congress acts this summer, the mission will crash-land about five billion kilometers short of its goal.



PLUTO, the last unexplored planet.

The question before Congress is whether to go along with a Bush administration decision to abort the Pluto project altogether. The president's budget for fiscal year 2003 excludes it. A similar situation arose last year, when the administration left Pluto out of the budget and Congress put it in.

The administration's position is clear and, for the most part, compelling: NASA programs that are well managed get rewarded; those that aren't get rethought. Overall, planetary exploration falls into the first category, and the administration plans to increases its budget by 50 percent between 2002 and 2006. But the outer-planets part of the program, plagued by cost overruns, has fallen into the second category.

To fix it, the administration has relaunched the outer-planets program as New Frontiers, modeled on NASA's lauded Discovery program. New Frontiers will solicit mission proposals, choose among them in a competitive process and impose a strict cost cap ($650 million over four years). Meanwhile NASA will invest in the development of new propulsion technologies. To guide the selection of destinations, a National Research Council panel is now preparing a prioritized list.

The plan is excellent, except for one thing. Where does Pluto fit in? As New Frontiers now stands, Pluto mission planning would have to start from scratch, and a spacecraft couldn't possibly hit the pad before 2007. It would then miss the crucial launch window in January 2006, when Jupiter has the right alignment for a slingshot maneuver that would catapult the spacecraft to Pluto. The next window is not until 2018.

Officials point out that the new propulsion technologies could obviate the need for a slingshot, but those systems wouldn't be available until late this decade, if then. And with every day that passes, Pluto gets colder, darker and harder to study. In a poll by their professional society this past January, planetary scientists ranked Pluto as the top priority for a mission.

Fortunately, there is a straightforward solution. Last year NASA, frustrated by its own difficulties in designing a frugal Pluto mission, solicited proposals from the outside, chose among them in a competitive process and imposed a strict cost cap of $500 million. The winner, known, confusingly, as New Horizons, is thus a New Frontiers mission in all but name [see "Journey to the Farthest Planet," on page 56]. It could simply be rolled into the New Frontiers program, just as older missions were absorbed into the Discovery program.

Congress would only have to reshuffle some funding. NASA has already spent $30 million on New Horizons. Next year it would need about $110 million more than what the president's budget has proposed. But over the three subsequent years, the agency would actually need $300 million *less* (including money set aside for operating expenses). Everyone wins: the taxpayer pays extra now but makes it up (plus some) later on, the Pluto mission can depart on schedule, and policymakers will strike another blow for good management at NASA.

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DON DIXON (*artist's conception*)

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FEATURED THIS MONTH

Visit www.sciam.com/explorations/ to find these recent additions to the site:

More Misleading Math about the Earth

In our January issue, experts on global warming, energy, population growth and biodiversity charged statistician and political scientist Bjørn Lomborg with being out of touch

with the facts. They alleged that his book, *The Skeptical Environmentalist*, wrongly uses statistics to dismiss warnings about peril for the planet.

The debate continues this month in print and online. See page 10 for more reactions from editors and readers and visit the Web site for additional coverage, including Lomborg's response to the criticism.

Tabletop Nuclear Fusion

Did physicists achieve nuclear fusion in a beaker on a laboratory bench? One team says yes, but another group could not replicate the results. What is certain is that the report has attracted plenty of controversy.

Language and Thought

Researchers studying a range of topics—from children's hand gestures to grammatical rules for forming plurals—argue about whether a person's native tongue influences the way he thinks.

ASK THE EXPERTS

How do volcanoes affect the world's climate?
Karen Harpp, assistant professor of geology at Colgate University, responds.
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Letters

EDITORS@SCIAM.COM

SEVERAL CONTROVERSIAL January articles drew abundant mail, but "Misleading Math about the Earth," criticizing Bjørn Lomborg's book *The Skeptical Environmentalist*, led the pack in volume and venom. Many dismayed readers wrote to express their angry (though misplaced) concern that Lomborg would not be allowed to reply to his critics. As planned, however, Lomborg's reply can be found on page 14 and at www.sciam.com, along with responses to his rebuttal arguments.

Some of the mail relating to "Misleading Math" is included in this section; more is on our Web site. Below, readers also comment on other, less inflammatory subjects from the January issue, such as human cloning and nuclear energy.

TO CLONE OR NOT TO CLONE

I was dismayed to see your article on the all-but-failed attempt at cloning human embryos conducted by Advanced Cell Technology ["The First Human Cloned Embryo," by Jose B. Cibelli, Robert P. Lanza and Michael D. West, with Carol Ezzell]. In ACT's study, published in *e-biomed: The Journal of Regenerative Medicine* in November 2001, the authors transferred nuclei from somatic cells into enucleated human oocytes. The great majority of embryos did not divide even once.

Only three of the 19 reconstructed embryos divided once, and just one developed into the miserable-looking, abnormal six-cell embryo that was displayed on your issue's cover. Because expression of the genome in normal embryos does not even begin before the four- or five-cell stage, development of a single transferred embryo to a six-cell stage is a totally uninformative result and argues merely that the authors were successful in killing every reconstituted embryo.

The discussion on therapeutic cloning is important and raises complex scientific and ethical issues. It is crucial that this debate is based on solid scientific evidence and not on third-rate science.

RUDOLF JAENISCH
Whitehead Institute for Biomedical Research
Professor of Biology,
Massachusetts Institute of Technology

EZZELL REPLIES: Cibelli, Lanza and West were the first to report cell division after transplanting a nucleus from a human body cell into a human egg—a process generally referred to as cloning. [The three-in-19 figure Jaenisch cites is misleading: only eight cells were injected with ovarian cumulus cells, the ones shown to be most effective in mice.] Whether or not the genes in the transplanted nuclei were active is unknown; researchers disagree on when genes normally become active following fertilization.

The publication of our article has already fostered a wide discussion of cloning, and it is difficult to see how any of the weaknesses Jaenisch cites have damaged that discourse.

The heated controversy regarding the need for therapeutic cloning is based on the belief that embryonic stem (ES) cells, on being allotransplanted, will inevitably be rejected by the host. In fact, the unique immunological characteristics of stem cells and ES cells indicate that they may be immunologically tolerated by allogeneic or even xenogeneic hosts and, surprisingly, that such tolerance may last even after these stem cells have differentiated and matured inside the hosts. Although the precise immunological mechanism has yet to be elucidated, there may be some analogy to that seen in a normal pregnancy. Clearly, we should keep an open mind about how essential therapeutic cloning has to stem cell research.

RAY C. J. CHIU
McGill University

NUCLEAR POWER: THE FIGURES, THE FUTURE

Those who believe that nuclear power is too costly should consider recent data [Perspectives]. For the first time in a

decade, total production costs at U.S. nuclear plants are lower than those at fossil-fuel plants. In 1999 production costs at U.S. nuclear plants averaged 1.83 cents per kilowatt-hour, compared with 2.07 cents for coal plants, 3.18 cents for oil-fired plants and 3.52 cents for natural gas plants.

We would most likely pay more for electricity from a new nuclear plant than we would for electricity from a new coal or gas plant. But if the true cost of coal electricity were calculated—if the "costs" of global-warming effects, acid rain, premature inhalation deaths, coal miner deaths and coal miner black lung disease and so on were included—nuclear electricity would win that economics race by far.

MAX CARBON, Emeritus Chair
MICHAEL CORRADINI, Chair
College of Engineering
University of Wisconsin–Madison

Our near-total dependence on fossil fuels may seem to require a complicated explanation, but it is really very simple ["Next-Generation Nuclear Power," by James A. Lake, Ralph G. Bennett and John F. Kotek]. Conservatives blocked the regulatory and tax policies that would have promoted energy efficiency and renewable energy, and liberals blocked nuclear power. The only thing that got past both vetoes was fossil fuels.

The issue should not be nuclear versus renewable but carbon-emitting versus carbon-free. I can envision advanced nuclear power in tandem with solar and wind combining to provide the needed mix of base-load and peak power while displacing oil and coal.

JOHN ANDREWS
Sag Harbor, N.Y.

ECONOMIC FAIRNESS AND THE INDIVIDUAL

Although I find plausible and convincing the discoveries of Karl Sigmund, Ernst Fehr and Martin A. Nowak ["The Economics of Fair Play"] indicating that most individuals consider fairness along with monetary gains in playing economics games, the authors have omitted one important point. Theologian Reinhold Niebuhr in his book *Moral Man and Immoral Society* draws a radical distinction between individual and national morality. This same distinction must also be drawn, with the megacorporation replacing the nation, in the economic sphere. The large corporations that dominate our economy do not have any regard for fairness, only profit. The failure to acknowledge this reality makes the authors' results largely irrelevant to the functioning of existing economies.

CHRISTOPHER SHERMAN
Andover, Mass.

When a responder in the Ultimatum Game passes up $20 in order to punish the proposer for taking $80, the authors propose that this is an emotional (and, by implication, irrational) response to social conditioning. They overlook the possibility that this is instead a superrational response. A responder who forgoes immediate gratification to punish a greedy proposer is reacting to the logic that excessive greed is bad for society. Intuitively, if not consciously, the responder knows that if greed is regularly punished, then society as a whole will benefit, and the individual will benefit as a result.

DANIEL R. HICKS
Byron, Minn.


NUCLEAR POWER PLANT near Phoenix, Ariz.

ARIZONA PUBLIC SERVICE

READERS RESPOND TO "MISLEADING MATH ABOUT THE EARTH"

Contrary to what Stephen Schneider maintains ["Global Warming: Neglecting the Complexities"], Bjørn Lomborg relies on the Intergovernmental Panel on Climate Change for virtually all his scientific information and makes no effort to distort the range it proposes. He does, however, go beyond the Summary for Policymakers to review the scientific chapters themselves, and he does, appropriately, consider new work that might alter IPCC claims—work that the IPCC itself cites.

One small point of personal interest to me illustrates the rather strained nature of the attacks on Lomborg. Schneider claims that Lomborg cites a paper by my colleagues and me on what we refer to as the iris effect. Lomborg points out that our paper "might pose a challenge" to the IPCC range. Schneider goes on to chide Lomborg for failing to present an allegedly fatal flaw in our argument: that it is simply the extrapolation from "a few years of data in a small part of one ocean."

What Schneider really demonstrates is that he completely misunderstands what we have done, which is to assess the effect of temperature on the behavior of cumulonimbus convection and its impact on large-scale upper-level cirrus clouds in the tropics. The primary requirement of such a study is that it deal with a period and a region that contain a large enough number of cumulonimbus towers; the results are then scalable to the entire tropics—a far cry from naive extrapolation. The period we dealt with (20 months in the paper, but now extended to four years) and the area we looked at (30 degrees south to 30 degrees north and 130 degrees east to 170 degrees west) amply satisfied this criterion. As our paper emphasizes (and as Lomborg acknowledges), there

remain uncertainties in our work, but Schneider's concern over "extrapolation" is not one of them.

RICHARD S. LINDZEN
Alfred P. Sloan Professor of Meteorology
Massachusetts Institute of Technology

As an economist, I would not presume to second-guess findings that reflect the established body of scientific opinion, especially when that opinion is expressed in tentative terms. I make use only of those findings that have been published in the scientific literature by widely respected academic researchers. There are no references in my books to publications from environmental lobbies and think tanks; I avoid them not because they are necessarily wrong but because I fear their claims may be overly influenced by their commitment to advocacy. In short, not being an ecologist, I can't afford the risk of basing anything on estimates published exclusively by advocacy groups, of whatever complexion.

Lomborg's remarkable achievement has been to collate a number of the most outlandish assertions made by advocacy groups, along with truncated estimates and doctored claims from the scientific literature, so as to create such an effective smoke screen of statistics, references and footnotes that the nonscientist reader is led to believe that the bundle Lomborg offers represents a solid scientific critique of the scientific establishment.

PARTHA DASGUPTA
Frank Ramsey Professor of Economics
University of Cambridge

Thomas Lovejoy complains that Lomborg does not know the difference between extinction facts and extinction projections ["Biodiversity: Dismissing Scientific Process"]. But that is precisely Lomborg's point: that the projections are based on a circular argument behind which are few or no data. Lomborg describes how Norman Myers's immensely influential estimate of 40,000 extinctions a year migrated through the literature from assumption to "fact" without any contact with data on the way. Lovejoy confirms this by admitting that "Myers did not specify the method of arriving at his estimate."

In the accompanying editorial, John Rennie accuses Lomborg of not seeing the forest for the trees. Any reader of the book will see that the exact opposite is true. Lomborg puts the claims of environmental pessimists in context, in many cases simply by graphing a longer run of data than that chosen by the pessimist. Rennie pretends that the articles he has commissioned are defending science. They read more like defending a faith—a narrow but lucrative industry of environmental fund-raising that has a vested interest in claims of alarmism.

Lomborg is as green as anybody else. But he recognizes that claims of universal environmental deterioration not only have often been proved wrong but are a counsel of despair that distracts us from the ways in which economic progress can produce environmental improvement as well.

MATT RIDLEY
Newcastle, England

I read *The Skeptical Environmentalist,* and Lomborg misunderstands and misrepresents the state of the science related to my field of interest: freshwater resources. Indeed, he misuses my research on global water problems. He misquotes my analyses of trends in populations worldwide without access to clean water and sanitation services, using data that are a decade old. He selectively focuses on the issue of water scarcity—a subject of considerable debate even in the water community—but fails to address trends in water-related diseases. He ignores evidence about deteriorating fisheries and wetland habitat. He glosses over unsustainable groundwater use. He selectively quotes data that support his precepts but ignores data that contradict them. He combines different types of data that are not comparable.

This is not the place for a comprehensive summary of Lomborg's errors, but I would note that interested readers can find other scientific reviews at www.pacinst.org/Lomborg_review.html and at www.ucsusa.org/environment/lomborg.html

PETER H. GLEICK
Director, Pacific Institute for Studies in Development, Environment, and Security
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Lomborg has tried to encapsulate in one volume the scientific evidence and conclusions about the most important subject of our time: the influence of man on the state and future of our planet.

"Lomborg creates such a smoke screen of statistics, the nonscientist reader is led to believe that what he offers is a solid scientific critique."

Whether or not he succeeds is yet to be determined. The details will be hammered out in peer-reviewed studies based on painstaking observations, inevitably containing some errors, resulting in theories that are subject to change. The uncertainty of future predictions ensures that there never is a "right" answer.

This debate is in the finest tradition of science and could be presented in no better forum than *Scientific American.* Bravo!

FRED PETERS
Lancaster, Va.

ERRATA In "Next-Generation Nuclear Power," last year's rolling electrical blackouts in California were said to have taken place in the summer; actually, they ceased in May.

In "Seeing the Invisible," by Diane Martindale [Staking Claims], the photograph of liquid crystals should have been credited to Oleg Lavrentovich of Kent State University.

The Skeptical Environmentalist Replies

Recently *Scientific American* published "Misguided Math about the Earth," a series of essays that criticized **Bjørn Lomborg's** *The Skeptical Environmentalist*. Here Lomborg offers his rebuttal

After *Scientific American* published an 11-page critique of my book *The Skeptical Environmentalist* in January, I've now been allowed a one-page reply. Naturally, this leaves little space to comment on particulars, and I refer to my 32-page article-for-article, point-for-point reply at www.lomborg.org and on the *Scientific American* Web site (www.sciam.com).

I believe many readers will have shared my surprise at the choice of four reviewers so closely identified with environmental advocacy. *The Economist* summarized their pieces as "strong on contempt and sneering, but weak on substance."

The book was fundamentally misrepresented to the readers of *Scientific American*. I would therefore like to use this opportunity to stake out some of the basic arguments.

I take the best information on the state of the world that we have from the top international organizations and document that generally things are getting better. This does *not* mean that there are no problems and that this is the best of all possible worlds, but rather that we should not act on myths of gloom and doom. Indeed, if we want to leave the best possible world for our children, we must make sure we first handle the problems where we can do the most good.

Take global warming, where Stephen Schneider berates me for neglecting and misunderstanding science and failing to support the Kyoto Protocol. But in my book I clearly use the U.N.'s Intergovernmental Panel on Climate Change (IPCC) as key documentation, and all the uncertainties notwithstanding, I accept that science points to anthropogenic global warming. (This is in contrast to the contrarians who deny global warming or indeed to early work of Schneider, who suggested that we could be heading for a new ice age.)

Schneider claims that I don't understand the research in studies by Richard S. Lindzen and by the Danish solar scientists. Yet Lindzen replies: "… at one fell swoop, Schneider misrepresents both the book he is attacking and the science that he is allegedly representing." And the solar scientists: "It is ironic that Stephen Schneider accuses Lomborg of not reading the original literature, when in his own arguments against Lomborg he becomes liable to similar criticism."

With global warming our intuition says we should do something about it. While this intuition is laudable, it is not necessarily correct—it depends on comparing the cost of action to the cost of inaction and the alternative good we could do with our resources. We should not pay for cures that cost us more than the original ailment.

The Kyoto Protocol will do very little good—it will postpone warming for six years in 2100. Yet the cost will be $150 billion to $350 billion annually. Because global warming will primarily hurt Third World countries, we have to ask if Kyoto is the best way to help them. The answer is no. For the cost of Kyoto in just 2010, we could once and for all solve the single biggest problem on earth: We could give clean drinking water and sanitation to every single human being on the planet. This would save two million lives and avoid half a billion severe illnesses every year. And for every following year we could then do something equally good.

Schneider tells us that we need to do much more than Kyoto but does not tell us that this will be phenomenally more expensive. His attitude is the sympathetic reaction of a traditional environmentalist: solve the problem, no matter the cost. But using resources to solve one problem means fewer resources for all the others. We still need the best information on science, costs and benefits.

Take biodiversity. Thomas Lovejoy scolds me for ignoring

GERRY ELLIS *Minden Pictures*

loss of species. But no. I refer to the best possible U.N. data, and I accept that we are causing species extinction at probably about 1,500 times the natural rate. But unlike the traditional environmentalist who feels we have to do whatever is needed to stop it, I also ask how big this means the problem is. Answer: Over the next 50 years we might lose 0.7 percent of all species. (This contrasts both to contrarians who deny species extinction and to Lovejoy's wildly excessive warning from 1979 of a 20 percent species loss from 1980 to 2000.) By the end of this century the U.N. expects we will have *more* forests, simply because even inhabitants in the developing countries will be much richer than we are now. Thus, the species loss caused by the real reduction in tropical forest (which I acknowledge in the book) will probably not continue beyond 2100.

Take all the issues the critics *did not even mention* (about half my book). We have a world in which we live longer and are healthier, with more food, fewer starving, better education, higher standards of living, less poverty, less inequality, more leisure time and fewer risks. And this is true for both the developed and the developing world (although getting better, some regions start off with very little, and in my book I draw special attention to the relatively poorer situation in Africa). Moreover, the best models predict that trends will continue.

Take air pollution, the most important social environmental indicator. In the developed world, the air has been getting cleaner throughout the century—in London, the air is cleaner today than at any time since 1585! And for the developing countries, where urban air pollution undeniably is a problem, air pollution will likewise decline when they (as we did) get sufficiently rich to stop worrying about hunger and start caring for the environment.

While I understand the traditional environmentalist's intuitive abhorrence of prioritization, I believe that the cause of environmentalism is not well served by the *Scientific American* feature, clearly trying to rubbish the whole project. If we want to build an even better tomorrow, we need to know both the actual state of the world and where we can do the most good. I have made an honest effort to provide such an overview, based on science and with all the references clearly indicated.

JOHN RENNIE, EDITOR IN CHIEF OF SCIENTIFIC AMERICAN, REPLIES:

Disappointingly, Lomborg has chosen to fill his print response with half-truths and misdirection. Perhaps in this brief space he felt that he could do no better, but critics of The Skeptical Environmentalist *also find such tactics to be common in his book. He implies that he has been wronged in getting so little space; our 11-page set of articles is a response to the 515-page volume in which he made his case, and which was widely and uncritically touted in the popular media. (Long before our article, for instance,* The Economist *gave him four unanswered pages for an essay.) So far it is the scientists who are having a harder time getting equal space for their side. Anyone still interested in this controversy will find on www.sciam.com our original articles and Lomborg's detailed rebuttal of them, along with refutations to his rebuttal.*

Lomborg and The Economist *may call them "weak on substance," but our pieces echo identical criticisms that have been made in reviews published by* Nature, Science, American Scientist, *and a wide variety of other scientific sources—not venues where insubstantial criticisms would hold up.*

Lomborg's stated proof that he understands the climate science is that he relies on the IPCC's report, but the argument of Schneider (and other climatologists) is of course that Lomborg picks and chooses aspects of that report that he wants to embrace and disregards the rest. Lomborg boasts that he isn't a global-warming denier, but how is that relevant? The criticism against him is not that he denies global warming but that he oversimplifies the case for it and minimizes what its consequences could be. The reference to Schneider's theories about global cooling reaches back three decades; all good researchers change their views as new facts emerge. How does this bear on the current debate except as personal innuendo?

As in his book, Lomborg repeats that the Kyoto Protocol would postpone global warming for only six years. This is an empty, deceptive argument because the Kyoto Protocol isn't meant to solve the problem by itself; it is a first step that establishes a framework for getting countries to cooperate on additional measures over time. The cost projections Lomborg uses represent one set of estimates, but far more favorable ones exist, too. Given that the additional anti-warming steps that might be taken aren't yet known—and so their net costs are impossible to state—it is premature to dismiss them as "phenomenally more expensive."

As Lovejoy's article and others have noted, Lomborg's simplistic treatments of biodiversity loss and deforestation are inappropriately dismissive of well-grounded concerns that those numbers could range far higher. (And why resurrect a claim in a paper that Lovejoy wrote 23 years ago when he and others have far more recent estimates?) Moreover, one problem of Lomborg's statistical methodology is that it tends to equate all items within a category regardless of how valuable or different the individual elements are. For example, there may be more forest in 2100 than there is today, but much of that will be newly planted forest, which is ecologically different (and less biodiverse) than old forest.

When Lomborg restates the number of lost species as a percentage of total species, is he simply showing the true size of the problem or is he perhaps also trying to trivialize it? By analogy, in 2001 AIDS killed three million people, with devastating effects on societies in Africa and elsewhere. But that was only 0.05 percent of all humans. Which number is more helpful in setting a public health agenda for AIDS? The answer is neither, because numbers must be understood in context; Lomborg creates a context for belittling extinction problems.

Lomborg is being disingenuous when he protests that our authors did not even mention half his book. As our preface to the feature stated, we asked the authors to comment specifically on just four chapters. The flaws in those sections alone discredit his argument.

Environmental scientists are all in favor of setting priorities for action; Lomborg pretends otherwise because he disagrees with the priorities they set. Even if his effort to describe the "actual state of the world" (a naive goal, given the world's complexity and the ambiguity of even the best evidence) is honest, his argument is not credible. And by sowing distrust of the environmental science community with his rhetoric, Lomborg has done a severe disservice not only to those scientists but also to the public he has misinformed. SA

50, 100 & 150 Years Ago

FROM SCIENTIFIC AMERICAN

Stellar Theory ▪ Earthly Disaster ▪ Ancient Mystery

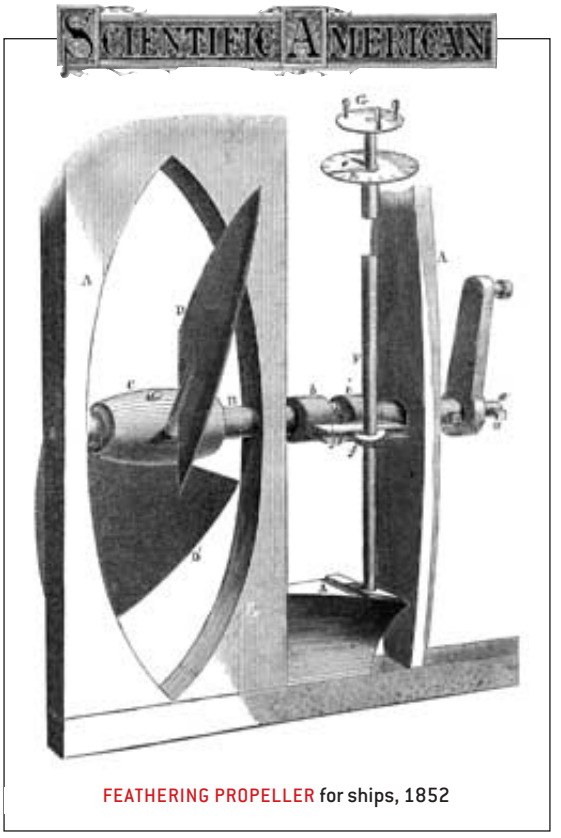
MAY 1952

GOLDEN GLOVES—"Professional boxers usually come from the lowest income groups. Two sociologists reasoned that as one ethnic group replaces another near the bottom of the socioeconomic ladder, its young men become dominant in the ring. According to the statistics collected, early in this century about 40 per cent of all professional boxers were Irish. In the 1920s and 1930s Jews and Italians took the lead. And by 1948 nearly half of all boxers were Negroes. Offered little but unskilled work, generally isolated from middle-class culture, slum boys are tempted by dreams of 'easy money' and quickly-won esteem, say the sociologists."

PLASMA MODELS—"We fill a small tank with mercury. Slow oscillation of an agitator, stirring the mercury at the bottom of the tank, will not disturb the surface of the mercury at the top of the tank. When a strong magnetic field is applied to the tank, however, the motion at the bottom is quickly communicated to the top. We have created a new kind of wave, which was predicted theoretically about 10 years ago but was produced for the first time in this experiment. The wave is the result of a coupling between magnetic and hydrodynamic forces. What has this to do with stars? It is possible to show that our mercury model reproduces many of the essential properties of stellar matter. It has always been assumed that the movement of gases in stars obeys the laws of hydrodynamics. But if a magnetic field drastically changes the properties of the dense stellar gases, as it does in the mercury model, then they must behave very differently from ordinary fluids. —Hannes Alfvén" [*Editors' note: Alfvén won the Nobel Prize in Physics in 1970 "for discoveries in magneto-hydrodynamics."*]

MAY 1902

VIOLENT ERUPTION—"Cable communication with Martinique was interrupted in the afternoon of May 6, and the next news filled the world with horror. An entire city of 28,000 inhabitants had been literally wiped out of existence. It is said that the whole top of Mont Pelée was blown off and fell in hot dust and shattered rock on the city of St. Pierre, while mud and lava poured out of the opening thus made. Volcanic eruptions are generally attributed to the expansion of moisture in the heated subterranean rocks. The original theory that the earth is a liquid mass covered by a thin crust of solid matter is now entirely discarded by scientists."



FEATHERING PROPELLER for ships, 1852

EASY COMMUTING—"One of the latest men of prominence to testify to the usefulness of the automobile to a business man is Mr. Henry Clay Frick, the well-known steel magnate of Pittsburgh. The millionaire is reported to have said the time saved him by the new means of locomotion amounts to at least half a million dollars yearly. It will not be long before the automobile will compete with the railroad, and the life of the cinder-begrimed commuter will be freshened by a rapid ride to business through the clear morning air from his country seat twenty-five to fifty miles away. Good roads are all that are needed to cause such prophecies to be realized."

MAY 1852

INGENIOUS PROPELLER—"The accompanying engravings are views of improvements in Screw Propellers, which have their blades adjustable in the hub, for the purpose of bringing the blades to a position to offer no material resistance to the progress of the vessel when under sail. Another principle is that, with the revolutions of the propeller stopped, it will act as a rudder and it will therefore serve to steer the vessel when under sail."

CHINA AND IRELAND—"A paper was read before the Belfast Literary Society in Ireland, on Chinese porcelain seals. About fifty of these have been found there, some in deep bogs, one in a cave, others scattered about. How they came there nobody can tell. They are of great antiquity. They have inscriptions on them in the ancient Chinese seal language, and Mr. [Rev. Dr. Karl] Gutzlaff had translated a number of them. Each seal is a perfect cube, with the figure of a Chinese monkey by way of a handle. It is supposed they may have been brought there by ancient Phoenicians, but it is our opinion that they were brought there by some of the ancient Irish tribes, who no doubt journeyed through China."

NEUROBIOLOGY

Peeling Plaque

RESEARCHERS REMAIN OPTIMISTIC ABOUT A VACCINE AGAINST ALZHEIMER'S **BY DIANE MARTINDALE**

Last fall a clinical trial got under way in the U.S. and Europe to test a hugely touted vaccine designed to reverse the course of Alzheimer's disease. In February that landmark trial came to an abrupt end after 15 patients fell ill with brain inflammation. The vaccine's maker, the Irish drug company Elan, has stopped giving the shots to its 360 volunteers while doctors determine what caused this serious side effect. Despite the setback, proponents of the vaccine still believe that the immune system can be taught to fight Alzheimer's—even if they aren't certain how the vaccine works.

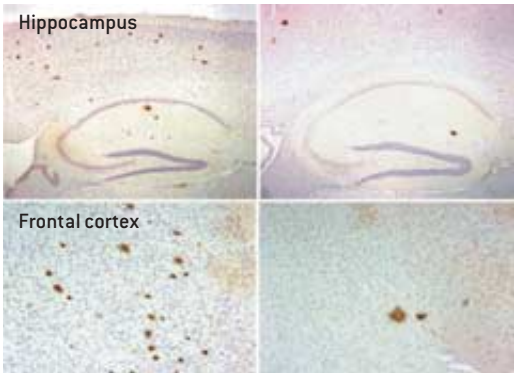
The Elan vaccine, referred to as AN-1792, is a synthetic version of the beta-amyloid protein. In Alzheimer's the protein becomes insoluble and accumulates as whitish plaques in the brain, thereby leading to nerve cell damage and dementia.

In 1999 Dale B. Schenk, now a vice president at Elan, announced that experiments in mice with AN-1792 suggested that it could halt and perhaps even cure Alzheimer's. Since then, it has been shown that vaccinated mice genetically engineered to develop the human disease make antibodies that not only prevent the sticky protein from accumulating in the brain but also help to clear existing amyloid plaques.

Just how antibodies remove plaques remains unknown. The prevalent theory has been that antibodies against beta-amyloid are able to cross the blood-brain barrier. Then the antibody forms a complex with beta-amyloid that triggers microglia—support cells in the brain—to destroy the plaques.

The problem with this explanation is that antibodies are typically too large to cross the blood-brain barrier. So it is unlikely that this is the main mechanism by which the vaccine reduces amyloid pathology, notes David M. Holtzman, a neurologist at the Washington University School of Medicine. In his studies with mice, he found that only about 0.05 percent of all the antibodies circulating in the blood are found in the cerebrospinal fluid. "There aren't enough antibodies crossing the blood-brain barrier to activate microglia," Holtzman says.

New research indicates that antibodies don't need to go into the brain to clear amyloid plaques. Holtzman and others have strong evidence for the "sink" hypothesis, whereby antibodies bind beta-amyloid in the blood, outside the central nervous system. The blood then serves as a sink for beta-amyloid, pulling it from the brain and shifting the equilibrium in favor of the soluble protein over the plaque-associated insoluble form.



VACCINATED MICE (*right panels*) showed fewer amyloid deposits (*dark spots*) in their brains than their untreated brethren did (*left panels*).

CYNTHIA A. LEMERE

news SCAN

SCANNING FOR DEMENTIA

If a workable vaccine is developed for Alzheimer's, figuring out whom to inject won't be easy. Today every case of Alzheimer's is only a suspected case until a brain autopsy confirms the presence of amyloid plaques and tangles. But a new imaging technique could provide the early diagnostic tool needed. Scientists at the University of California at Los Angeles used positron emission tomography to image a novel radioactive tracer (called FDDNP). It honed in on the tangles of dead cells in the memory centers of the brains of nine living Alzheimer's patients. An autopsy after one patient died verified that the tracer had bound to plaques. The technique could help doctors diagnose the disease much sooner and monitor its progress while patients undergo treatment.

Holtzman's group found that after immunization, Alzheimer's mice had 1,000-fold more beta-amyloid in their blood compared with those that did not receive the vaccine. This surge in amyloid appears to be coming from the brain, Holtzman explains. And treated mice had far fewer amyloid plaques after five months than the control animals.

Cynthia A. Lemere, a neuropathologist at the Center for Neurologic Diseases at Brigham and Women's Hospital in Boston, has seen a similar sink effect in mice immunized with her beta-amyloid nasal vaccine, which is set to go into clinical trials at the end of this year. Most recently, Lemere discovered antibody-amyloid complexes in the spleen of vaccinated animals, indicating that antibodies bound to amyloid in the blood are being processed in the same way as any other antibody-bound protein. "This gives the sink phenomenon a big boost, but I'm not convinced it's the only mechanism," she says.

Indeed, the side effect seen in the Elan trial supports the idea that microglia are activated by some antibodies crossing into the brain. "The first reaction I always see after I vaccinate the mice is inflammation in the brain," notes neuroscientist David Morgan of the University of South Florida. "Patients in the Elan trial probably had a similar reaction." The inflammation does not kill the mice and eventually subsides as the microglia stop reacting to continued exposure to the vaccine. The Elan patients may have been fine had they been given enough time to let the swelling subside, he speculates.

Morgan's theory, though, won't be put to the test now that Elan has abandoned the trial. Patients who received AN-1792 will continue to be monitored to watch for additional side effects and to see if the injections had any benefit against Alzheimer's. The company has several other variations of the AN-1792 vaccine in the pipeline, and it hopes to test them in patients soon.

Still, even if these vaccines don't cause side effects the way AN-1792 has, many questions will have to be answered before an Alzheimer's vaccine is approved. The most alarming is whether the vaccine itself might cause neurodegeneration; beta-amyloid tends to stick together and might cause a "seeding" effect. "We haven't seen this side effect in the mice," Holtzman says, "but no one knows for sure."

Diane Martindale is a science writer based in New York City.

ECOLOGY

Lion versus Lamb

IN NEW MEXICO, A BATTLE BREWS BETWEEN TWO RARE SPECIES **BY KRISTA WEST**

What do you do when one rare, protected species threatens the livelihood of another, even more endangered species? In New Mexico shrinking ecological niches and fragmenting habitats have put two species on a collision course—and set state administrators and wildlife managers against one another in the courts. Here the state-protected mountain lion (*Puma concolor*) preys on the endangered desert bighorn sheep (*Ovis canadensis*). New Mexico officials recently voted for a plan to kill more mountain lions in an effort to protect more sheep.

There is good reason to worry about the state's sheep population. It has been steadily declining for decades and is one of the smallest in the Southwest, according to the U.S. Geological Survey. Only about 130 bighorns exist in the state, says the New Mexico Department of Game and Fish (NMDGF), which since the mid-1990s has tracked sheep populations using radio collars. Of the 40 sheep deaths the agency recorded during the study, 30 were caused by mountain lions. Richard Beausoleil, a biologist for the NMDGF, remarks that "the department was left with a choice: do nothing and watch populations of very limited species decline to extinction or control the dominant source of mortality."

According to the new regulation passed by the New Mexico Game Commission, which oversees the NMDGF, hunters will be allowed to kill 234 mountain lions (up from 176) when the season begins in October. They

WHO WILL WIN? Shrinking habitats have pit the rare mountain lion (*Puma concolor*) against the endangered desert bighorn sheep (*Ovis canadensis*). New Mexico plans to raise kill quotas for the lions.

will also be allowed to kill unlimited numbers on private lands, and each hunter will be allowed to take two lions (instead of the usual limit of one) in designated bighorn habitats. This extra removal of mountain lions, officials believe, will relieve predation pressures on the endangered sheep.

Opponents of the plan, including the nonprofit group Animal Protection of New Mexico, have filed a lawsuit to stop the hunts. The group acknowledges that something needs to be done to save the sheep but is concerned that the new kill quotas threaten the long-term survival of the predatory cats. Kenneth A. Logan, head of the NMDGF's 10-year study of lions, determined that no more than 11 percent of the state's lion population should be harvested each year. Animal Protection and others, however, estimate that the 234 kills could amount to 33 percent of the population, in contrast to the NMDGF's estimate of 10 percent. The problem is that because the cats are elusive, no one really knows how many of them there are—both estimates are based on mathematical models.

Ecologist Howard Passell of Sandia National Laboratories calls this management plan a "Band-Aid" fix. The real issue for New Mexico and other Western states, he argues, is how to manage these predator-prey relationships in the long run. Indeed, Logan suggests that culling those lions with a preference for sheep would be better than random removal by hunters. Logan's study, the most comprehensive of its kind, found that only a few cats developed a taste for bighorns. In the study, mule deer made up the bulk of the mountain lion's diet (up to 91 percent), whereas sheep constituted just 2 percent. But selective removal of the sheep-loving mountain lions is a difficult and expensive proposition.

D. J. Schubert, an independent wildlife biologist who is studying lion management policies in four Western states, says he does not "believe that a single Western state has the evidence necessary to justify its current mountain lion management practices." Many ecologists feel that the rules stem from an antiquated antipredator attitude. Schubert adds that "all Western states except California are allowing an unsustainable level of sport hunting." (California prohibits such hunting.)

What's needed to balance the interests of lions, sheep and humans is further research. Large, long-term studies of these complicated relationships are under way in California and Arizona, and the NMDGF is just beginning a DNA study of the state's lions to better estimate the size and range of the population. All hope that more information will lead to more effective management policies.

Krista West is a science writer living in southern New Mexico.

LICENSE TO KILL

Critics suggest that one reason New Mexico adopted the new regulations to raise kill quotas of mountain lions was to please the growing number of hunters. Permits have been steadily increasing over the past two decades. Most hunts are led by guides or outfitters that charge up to $3,000 a hunt. The hunting season runs from October through March.

Hunt Year	Licenses Issued	Total Harvest
1989–90	482	112
1990–91	781	108
1991–92	765	119
1992–93	826	105
1993–94	926	127
1994–95	1,145	150
1995–96	842	119
1996–97	980	177
1997–98	974	168
1998–99	1,485	153
1999–2000	1,702	156

SOURCE: The Status of the Mountain Lion in N.M., 1971–2000, *by Richard Beausoleil. New Mexico Department of Game and Fish, 2000*

TIM DAVIS *Photo Researchers, Inc.* (*left*); KEVIN SCHAFER *Corbis* (*right*)

Face Shift

HOW SLEEPING SICKNESS PARASITES EVADE HUMAN DEFENSES **BY LUIS MIGUEL ARIZA**

The fatal infection begins with the bite of a tsetse fly. The trypanosome parasite enters the bloodstream and starts to divide about every eight hours. The parasites stay in the bloodstream for months or even years, causing bouts of fever and headaches; sooner or later they invade the central nervous system, leading to coma and death. The single-celled protozoans survive for so long in the bloodstream by regularly acquiring new identities, thereby avoiding recognition and total elimination by the immune system. Surprisingly, the ability of the parasite to disguise itself resides in a transcriptional body discovered in the protozoan's nucleus.

The parasite shifts its coat by altering a protein called variant surface glycoprotein (VSG). It can express this type of protein from 1,000 different genes scattered across 20 sites on different chromosomes. Miguel Navarro, now at the CSIC Institute of Parasitology and Biomedicine in Granada, Spain, and Keith Gull of the University of Manchester in England conclude that the newly discovered transcriptional body reads one of these genes, much as the laser of a CD player plays back one track of a disc. Each gene represents a VSG alternative—a different melody—for the protozoan to express. "We believe a unique expression body does the job, attaching to any of these chromosome sites and transcribing only one VSG type at any time," Navarro explains. This body, which the team was able to localize in the nucleus by using fluorescent protein markers, was detected only when the parasite was in the bloodstream.

More bizarre is how the trypanosome reads the DNA of the VSG genes. All eukaryotes (organisms with nuclei in their cells) use a molecular translator enzyme called RNA polymerase II to read the genes that are expressed into proteins. The trypanosome, which branched from other eukaryotes 300 million years ago, breaks this universal rule. Navarro and Gull found that the transcriptional body of the parasite uses a less abundant type of enzyme called RNA polymerase I to read the VSG genes. RNA polymerase I was never known to read genes for proteins—all other eukaryotes use the enzyme solely to produce ribosomal RNA (which creates ribosomes, the cell's protein-making factories).

Navarro suggests that humans might have a similar type of nuclear body. Like the trypanosome's VSG coat, the immune system's B lymphocytes also express one protein (immunoglobulin) on their surface at a time, even though each B cell has many different genes for the surface proteins. The genes for the receptors of olfactory cells might also be read in a similar way.

INVADED: At about 20 microns, the trypanosome parasite is nearly three times as long as a human red blood cell.

Etienne Pays, a parasitologist at the Free University of Brussels, is skeptical of the idea that a new transcriptional body is in human cells. He notes that its existence "would be only expected provided that polymerase I is also used to transcribe normal genes, and so far there is no example of this kind." Moreover, "we would want to see what that structure looked like in the electron microscope," says Peter Cook, an expert on molecular transcription at the University of Oxford. "Otherwise it might be just an accumulation of the polymerase and associated genes and be like other regions of the nucleus."

Nevertheless, the study richly illustrates the picture of a well-organized nucleus. It may also have broad implications for more effective treatments for the parasitic disease. "Hitherto, we have thought of the nucleus as a bag full of genes and enzymes," Cook notes. "But now there are structures, too, and we can, in principle, interfere with the structure and so interfere with the function" of the deadly parasite.

Luis Miguel Ariza is a writer based in Madrid. In the May 2001 issue he described how reserves may increase animal deaths.

SPREAD OF A DEADLY SLEEP

The World Health Organization estimates that the trypanosome, the sleeping sickness parasite, kills some 66,000 Africans annually and that around 500,000 people could be infected, mostly in poor, rural areas. In certain villages of Angola, Congo and southern Sudan, sleeping sickness affects 20 to 50 percent of the population, making it a leading cause of mortality, ahead of AIDS. Drug treatments work best in the initial stages, although early diagnosis is often difficult.

OLIVER MECKES AND NICOLE OTTAWA *Photo Researchers, Inc.*

AMATEUR SCIENCE

R.I.P. for D.I.Y.

SCIENCE TINKERERS CONTINUE TO TAKE IT ON THE CHIN **BY GEORGE MUSSER, KF6LOJ**

Several years ago I walked into Fry's Electronics in Palo Alto, Calif., and asked for an inductor. It is hardly an unusual electronic component; every radio project needs one. Yet the store clerks looked at me blankly. Fry's once had a reputation as the first stop for young engineers stocking a garage workshop. But in its components aisle, I found just a few bags of parts.

HAM RADIO remains a vibrant hobby, as is evident at flea markets such as this "Hamfest" in Clinton, N.J. But after a growth spurt in the 1990s, the number of amateur radio enthusiasts is starting to drop.

"The art of home-brewing one's own electronic equipment is pretty much a lost one," says Chuck Penson, a radio ham in Tucson, Ariz. The D.I.Y. movement that spawned the computer revolution—and inspired untold numbers of tinkerers to pursue careers in science—has stopped moving. Heathkit ceased making its electronic kits 10 years ago. *Popular Electronics* and *Byte* magazines have hung up their soldering irons. Meccano, the maker of Erector sets, went bankrupt in 2000. Last year *Scientific American* dropped the Amateur Scientist column, citing a long decline in readership, and Edmund Scientific sold off its consumer catalogue and shut its famous retail store in Barrington, N.J.

"It was a Mecca for the science enthusiast," recalls Nicole Edmund, vice president of marketing and sales at Edmund Industrial Optics and granddaughter of the company's founder. But the store's sales had been drooping for most of the past decade, she says, and the company wanted to focus on its more profitable optics business.

What we seem to have witnessed is the fragmentation of amateur science. Heathkit, for example, appealed to a broad range of people. Some built kits for kits' sake. Others just wanted to save money: Heathkits were usually cheaper and better than store-bought radios or TVs. As manufacturing costs went down and quality went up, though, off-the-shelf products gained the advantage. The same went for telescopes and most other gizmos. "When I got started, I could not have purchased what I could have built," says Dennis DiCicco, an editor at *Sky & Telescope* magazine. "Today if you want a telescope, you can afford one. You're not going to save much money if you build one."

As the market split between craftsmen and appliance owners, magazines had to adapt or die. In the late 1970s computer hobbyists of all ability levels devoured *Byte*. As PCs went mainstream, the magazine played down home-brew projects. Advanced amateurs, meanwhile, outgrew the projects and gravitated to niche publications. *Circuit Cellar,* started by ex–*Byte* columnist Steve Ciarcia, succeeded with a new publishing model: as its readers became more sophisticated, so did the articles. "I saw that you had to move upscale with them, or they'd move away from you," Ciarcia says.

Indeed, dedicated amateurs are now quasi-professionals. The Society for Amateur Scientists conference taking place next month in Philadelphia will have sessions on how to publish your research and how to claim a tax deduction for your basement lab. Discoveries by amateur astronomers have made headlines. At the other end of the market, people with an occasional science craving can satisfy it at, say, the Nature Company. And for those who fall in the middle, a few kit suppliers (especially in robotics and music production) and magazines (such as *Nuts & Volts* and *Poptronics,* formerly *Radio Electronics*) carry on.

Evidently, the something-for-everyone model epitomized by Heathkit and the Amateur Scientist column can't compete anymore. Specialized sources and Internet newsgroups cater to each skill level. But much of the mentoring and serendipity that the diverse community of amateurs offered has been lost. It is hard not to regret its passing.

SCIENCE'S NEXT GENERATION: AT RISK?

Electronics tinkerers, software hackers and radio hams have long played crucial roles in the development of modern technology. Will they continue to? In the near term, the answer is clearly yes. Steve Ciarcia, editor of *Circuit Cellar* magazine, says that most of his 30,000 subscribers work as engineers. Tinkering keeps them up-to-date. Yet these elite have left other amateurs so far behind that it is hard to draw new people into their ranks. Although Silicon Valley innovators often trace their career interest to childhood hobbies, those hobbies attract fewer of today's young people. Gordon West, a well-known ham radio instructor, says: "We're getting more kids than 10 years ago, but I don't think that ham radio will pull kids into the field like it used to."

PETER MURPHY

COMPLEXITY

When Markets Go Mad

PHYSICISTS TRY TO PREDICT WHEN STOCK PRICES WILL CRASH **BY DAVID APPELL**

About $4 trillion in market wealth vanished between the April 2000 bursting of the Nasdaq bubble and its recent stabilization at lower levels. Could investors have seen it coming? Better yet, could financial regulators have picked up on subtle clues and acted beforehand to prevent the crash? Perhaps. Researchers have found an increased level of predictability in certain complex systems just before large changes. Such changes, they say, can be the result of information encoded within the system's global state.

Systems composed of so-called agents that compete for limited resources and whose strategies evolve span a range of disciplines, such as economics, evolution, traffic analysis and network design (in which the agents of interest are, respectively, traders, species, drivers, and data packets). Extreme events in such systems, such as punctuations in evolution's equilibria or traffic jams during rush hour, are important because they are drastic and because they shape the system for a long time afterward. Whereas some extreme events are triggered by random, isolated incidents (such as the stock market's steep decline after September 11), others arise from forces internal to the system.

"In short, there is a collective, cooperative effect between the agents that, while involuntary, arises because they are all playing the same game," says Neil Johnson, a physicist at the University of Oxford. "Prior to the large change, they begin to form definite opinions about where they think the system is headed, and their collective action then dictates that a large movement will arise." Such effects go beyond the hallowed efficient market hypothesis, which states that at any given time security prices fully reflect all available information.

Because financial markets are complex systems with an immense number of variables, such as the history of all trades of all traders, econophysicists have for some years been studying a model called the minority game. In this model, players have limited memories, such as of the daily change in a market index, and must choose one of two alternatives at each step of the game—for instance, whether to buy or sell a commodity. Those who happen to be in the minority "win"; commodity buyers obtain a better price if there are more sellers than buyers. Johnson and his Oxford colleagues David Lamper, Paul Jefferies, Michael Hart and Sam Howison have further studied a binary aspect of the game: the up-and-down movements in a market irrespective of magnitude, which is simpler and computationally practical.

TRADERS all reacted the same way on April 14, 2000, causing the Nasdaq to plummet a whopping 361.58 points.

STEPHEN J. CARRERA *AP Photo*

The group's numerical simulations show that a complex system will often fall within a small "predictability corridor," with little variability in short-term behavior but with the internal dynamics to produce a sharp cascade. The scientists find that about half of large, extreme movements occur during such periods. In the predictability corridors, "we begin to have a population that not only sees the same pattern but is also going to respond in the same way to this pattern," Johnson says. The resulting loss of diversity drives agents to similar behavior. "We haven't got the balance of forces that we had before, the system becomes unstable, and a large change occurs."

While believing that the Oxford results amply demonstrate interesting new ideas, Robert Axtell, a fellow at the Brookings Institution, a multidisciplinary think tank in Washington, D.C., wonders about the extent to

WHEN PHYSICS GOES TO WALL STREET

Trying to forecast movements of financial markets using mathematical principles is nothing new. Researchers have postulated, for instance, that bond prices are "pulled" to values that are the "strange attractors" of complexity theory. Those who apply Elliot Wave Theory think that mass psychology pushes the markets into characteristic, repetitive patterns of waves reminiscent of the self-similarity of fractals.

The latest methods are built on "microscopic" models of markets and are a step beyond older, rule-of-thumb approaches. In addition to the extreme event technique developed by researchers from the University of Oxford, there is the method of Ricardo Mansilla of the National University of Mexico, who has applied tools from thermodynamics and statistical physics to make predictions similar to those of the Oxford group. In more controversial work, Didier Sornette of the University of California at Los Angeles has proposed that extreme events are preceded by oscillations that are apparent when time is looked at on a logarithmic scale.

which they can be generalized. "Since there are more losers than winners in the minority game, by definition, it's a poor model for a variety of strategic situations of relevance to people." Economists usually consider trade to be mutually advantageous to both sides, Axtell notes, meaning that all participants are winners; in biology, symbiosis similarly describes mutually beneficial interactions.

Still, there is growing interest in the emergence of cooperation in multiagent systems. A market regulator might pick up on underlying signals of an impending crash and take measures to maintain trading diversity and moderate changes. Systems of robots or satellites might be monitored not by a central controller subject to overloading but by agents programmed to compete to win by identifying gaps in a network.

The group's methods are now being tested against real financial data. Johnson says that in a test of the dollar-yen market, a correct prediction was made of "antipersistence," a tradable string of ups and downs that appeared in hourly market data and that persisted for six hours. A team at the Sony Computer Science Laboratories in Tokyo has since confirmed the prediction. "We see the dollar-yen result on real data as a necessary first step toward the Mecca of being able to predict large movements in real-world financial markets, which may last over many time steps," Johnson says.

You should, of course, consult a financial adviser before committing your money to the market. Soon you may want to consult a physicist as well.

David Appell is based in Gilford, N.H.

ECOLOGY

Drams of Drugs and Dregs

EXCRETED CHEMICALS POLLUTE U.S. STREAMS

BY REBECCA RENNER

Acetaminophen from painkillers, triclosan from antimicrobial soaps and caffeine from the morning java jolt, among other chemicals, are showing up daily on the banks of U.S. streams. The compounds, derived from substances that we excrete or use in our homes, farms and factories, were found by the first national stream survey designed to look for "contaminants of emerging concern"—tough-to-measure, relative newcomers to pollution monitoring.

Most of the chemical concentrations are tiny—less than one part per billion. But mixtures of many different chemicals are "surprisingly common," says U.S. Geological Survey hydrologist Dana W. Kolpin, who led the study that discovered seven or more compounds in half of the 139 streams. This snapshot is a worst-case scenario because the samples were taken downstream of sewage treatment plants and livestock feedlots, although a few contaminants turned up in more pristine sites.

Whether these nano-cocktails affect humans, animals or plants is pretty much a mystery. The biggest risk is to the aquatic environment, notes University of Florida zoologist Louis J. Guillette, Jr., because generations of fish and other water dwellers are ingesting the compounds 24/7. "These chemicals don't bioaccumulate, but they are used all the time and all over the place," he remarks. Indeed, the surveyed concentrations of high-potency female sex hormones, which originated in birth-control pills and hormone therapy, are high enough to cause deleterious effects in some aquatic organisms, explain Kolpin and his colleagues in the online March 15 *Environmental Science & Technology*.

This USGS survey missed the chemicals of perhaps greatest concern: antibiotics. Spilling over especially from animal feedlots and hospitals, they can lead to strains of bacteria resistant to their effects. Kolpin and his associates acknowledge that they underestimated antibiotic occurrence because they measured concentrations only in water; antibiotics tend to build up in mud and other sediments. The scientists hope to do a national sediment survey in the future.

Rebecca Renner, based in Williamsport, Pa., specializes in environmental issues.

STARBUCKS NATION? Minute traces of common compounds such as caffeine are finding their way into U.S. waters.

RON CHAPPLE *FPG International*

BY THE NUMBERS

Deindustrialization

WHY MANUFACTURING CONTINUES TO DECLINE **BY RODGER DOYLE**

Around 1970 the U.S. entered a new phase in which manufacturing, the engine of American prosperity, began to falter. The problem, felt particularly in the North, sometimes came with little warning to workers, as factories suddenly closed or moved to less unionized areas, such as the Sunbelt and overseas. More typically, however, there was a gradual reduction in Northern jobs as corporations failed to invest in improved plants and technology.

The U.S. lost 9 percent of its manufacturing jobs between 1967 and 2001, but in the industrial heartland—the Northeast and the Midwest—the loss reached more than 40 percent. Because of phenomenal increases in output per worker, manufacturing output rose sharply. But as the chart shows, a steadily decreasing proportion of American workers was employed in manufacturing. This process is markedly similar to the historical decline of farming, in which a progressively smaller number of people produced an expanding volume of goods.

The traditional argument for the cause of deindustrialization is competition from low-wage labor in developing countries. But according to a theory proposed by Robert Rowthorn of the University of Cambridge and Ramana Ramaswamy of the International Monetary Fund, deindustrialization is a natural consequence of economic progress in all developed economies. In their view, imports from developing countries have a relatively minor role; rather, faster productivity growth in manufacturing as compared with services plays the major part. Because factory procedures can be standardized more readily than those in the office and the store, manufacturing productivity rises far more quickly than productivity in the service sector. As manufacturing becomes more efficient, service industries absorb an increasing proportion of laid-off factory workers. This process is consistent with the tendency of middle-class consumers in affluent societies to spend an increasing portion of personal income on services as their appetite for goods nears satiation.

A theoretical implication of the Rowthorn-Ramaswamy thesis is that aggregate productivity growth of all sections of the economy could slow as workers shift to the less efficient service sector, a circumstance that could lead to a slowdown in the growth of living standards. A second implication is that as unionized factory workers shift to the service sector, which tends to be lower-paying and nonunionized, income disparities will increase—a result that apparently has happened.

Rowthorn states that in the U.S. the decline in manufacturing jobs has been unnecessarily accelerated by policy decisions, a position long held by American labor economists. Thomas Palley of the AFL-CIO, who accepts the logic of the Rowthorn-Ramaswamy thesis, believes that the absolute decline in U.S. manufacturing—2.5 million jobs in the last third of the 20th century—traces to, among other things, the perpetuation of an overvalued dollar, which makes it difficult for American goods to compete overseas, and to a U.S. policy that opens domestic markets while offering manufacturers incentives to move abroad.

Policy at the local level may have exacerbated the trend toward destabilization. New York City in the 1950s had the largest concentration of manufacturing jobs in the country, but the natural forces of deindustrialization were reinforced by the city's post–World War II policy of favoring "clean" businesses such as banks and brokerage houses. And so, instead of encouraging the preservation of well-paying factory jobs, the city promoted the biggest office-building boom on the planet. The number of manufacturing jobs, meanwhile, fell from almost a million in the 1950s to about 200,000 in 2001.

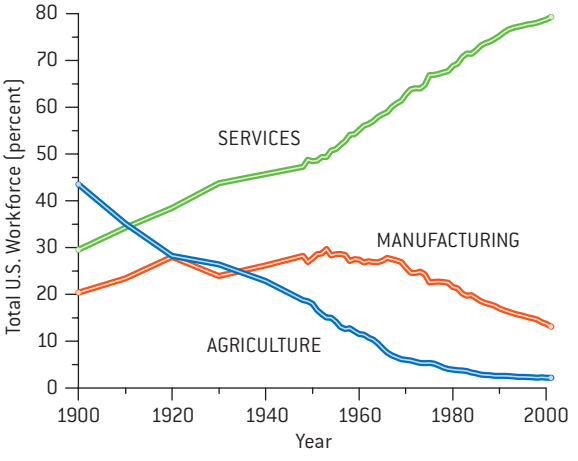
Next month: The link between deindustrialization and social pathology.

Rodger Doyle can be reached at rdoyle2@adelphia.net

NEED TO KNOW: WORK SHIFT

The winners and losers in manufacturing jobs in core counties, 1954–97:

San Jose, Calif.	+222,000
Orange County, Calif.	+200,000
Phoenix	+128,000
Jersey City, N.J.	–107,000
Newark, N.J.	–108,000
Pittsburgh	–139,000
Cleveland	–162,000
Philadelphia	–262,000
Detroit	–312,000
Chicago	–404,000
New York (5 counties)	–740,000



SOURCES: U.S. Bureau of the Census and U.S. Bureau of Labor Statistics

RODGER DOYLE

DATA POINTS: TOO MUCH OF A GOOD THING

Emotional appeals for blood donations after disasters are a poor way to collect blood and manage the supply, argues Paul J. Schmidt, a pathologist at the University of South Florida and a former blood bank official.

Approximate number of units of blood collected nationwide after the September 11 attacks: 475,000

Number used by victims: 258

Shelf life of whole blood: 42 days

Number of excess units the American Red Cross was able to freeze from its supply: 9,500

Number it had to discard: 49,860

Percent discarded: 17

Percent usually discarded: 3

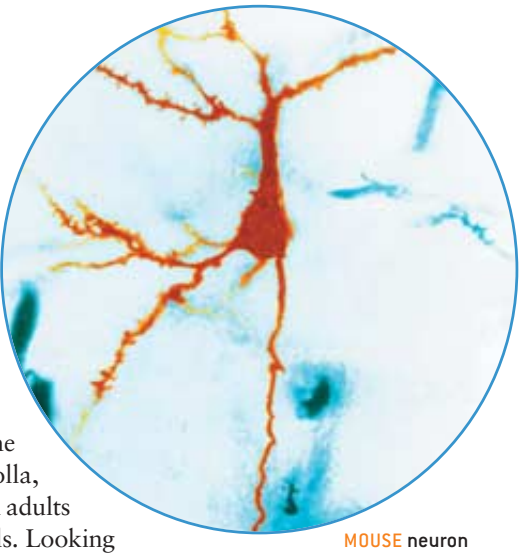
Estimated cost of collecting and processing excess blood supplies: $500,000

Number discarded does not include units delivered to hospitals but not used. Besides the Red Cross, America's Blood Centers and the American Association of Blood Banks collect and deliver supplies in the U.S.

SOURCE: Paul J. Schmidt in New England Journal of Medicine; *February 21, 2002*

NEUROBIOLOGY

As Good as Old



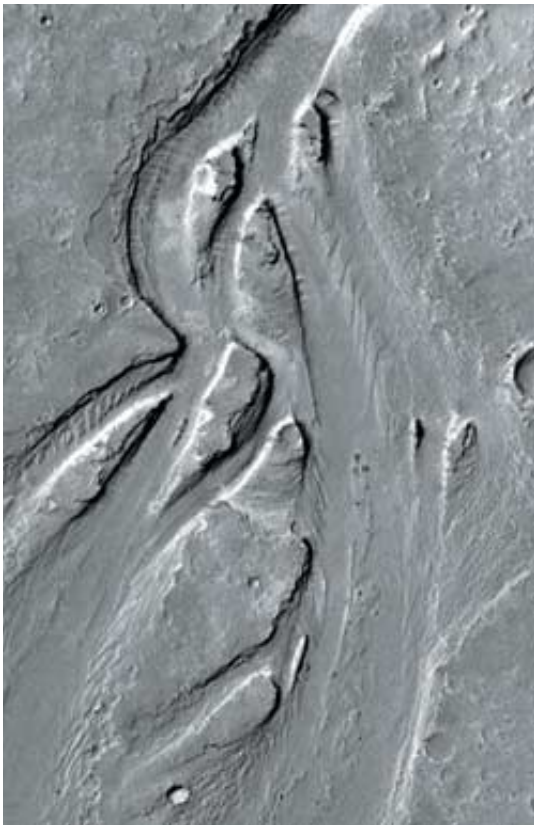
MOUSE neuron

Scientists have known for the past few years that adult brains can generate new neurons, but they were unsure how well those cells could operate. Fred H. Gage and his colleagues at the Salk Institute for Biological Studies in La Jolla, Calif., reported that newly created nerve cells in adults appear to be just as functional as older cells. Looking at adult mice, the researchers discovered that new neurons can eventually develop into forms similar to mature neurons and appear to integrate into the brain's electrophysiological network. The next question to ask, Gage says, is "How does the brain use these new cells? That's what we're working to try to figure out." The work appears in the February 28 *Nature*.

—Alison McCook

ASTRONOMY

Watered-Down Mars



RECENT FLOODING? Mars's Athabasca Valles region

Recent evidence from Mars supports the long-held theory that the Red Planet may harbor a great deal of water. The Mars Odyssey mission detected a substantial quantity of hydrogen in the surface of the planet's southern hemisphere, raising the possibility that the region may be home to a giant mass of ice.

Researchers presented this finding during a March press conference and plan to spend the next couple of years accumulating more data to better determine the amount and exact location of the ice. Additional evidence for a watery world comes from images from the Mars Orbital Camera. Analysis by Devon M. Burr and Alfred S. McEwen of the University of Arizona suggests that water flooded the planet's Athabasca Valles channel system as recently as 10 million years ago. Appearing in the January 15 *Geophysical Research Letters*, this result is the youngest dating for any large-scale Martian flood and indicates that there may still be groundwater deep below the dusty surface.

—Alison McCook

BSIP/SERCOMI *Photo Researchers, Inc. (top)*; IMAGE COURTESY OF MALIN SPACE SCIENCE SYSTEMS AND DEVON M. BURR ET AL. IN *GEOPHYSICAL RESEARCH LETTERS*, VOL. 29, NO. 1; JANUARY 15, 2002 *(bottom)*; ILLUSTRATION BY MATT COLLINS

EXTREME LIFE

A Crush on Bacteria

High-pressure living—the kind found in deep-ocean trenches, not on Wall Street—was once thought the province of only specially adapted, extreme-loving microbes. New evidence shows that even common bacteria, such as the ones in the human gut, can live a pressure-cooker life. Researchers at the Carnegie Institution of Washington squeezed two bacteria species—*E. coli,* which lines the intestines, and metal-loving *Shewanella oneidensis*—between diamond faces, generating pressures up to 16,000 times that found at sea level. Such forces, which turn liquid water into ice at room temperature, are found 50 kilometers below the earth's crust. The results, which appear in the February 22 *Science,* bolster the idea that life may exist in the deep ice of Antarctica or the Jovian moons Europa, Callisto and Ganymede. —*Charles Choi*

E. COLI can thrive whether deep in the intestines or deep in the earth.

PHYSICS

Cascades of Light

Lasers usually come in pristine colors of a single wavelength, but to detect trace chemicals or to send messages, researchers would like to tap a broader band of the spectrum. Bell Laboratories physicists have now adapted so-called quantum-cascade semiconductor lasers to do just that. They stack hundreds of standard semiconductor layers into 36 groups, each of which emits light over a narrow wavelength and is transparent to all others. Passing electrons give up their energy in a stepwise cascade, generating an infrared photon with each step. These photons clone themselves by bouncing back and forth through the stacks, to emerge as 1.3-watt laser light in a wavelength range between 6,000 and 8,000 nanometers. Even wider spectra should be possible, the authors predict. The research appears in the February 21 *Nature*. —*JR Minkel*

MEDICINE

Triggers against Transplants

Rejection is the main problem when it comes to grafting donated tissue, aside from the shortage of available organs. The triggers responsible for this lethal process, however, had eluded investigators. Now medical scientists at the University of Pennsylvania say otherwise harmless cells lining the blood vessels in grafted organs may activate immune system defenders known as killer T cells and cause chronic rejection. The researchers studying heart transplants in mice found that blood vessel cells in the donor organs can unwittingly trigger a direct attack from killer T cells. The attack scars the heart, and the risk of lethal complications increases steadily as artery walls thicken. Knowing the possible cause for rejection may lead to new strategies to muzzle the unwanted immune response. The findings are described in the March *Nature Medicine*. —*Charles Choi*

REJECTION OF ORGANS, such as this kidney, may be caused by blood vessel cells.

SCOTT CAMAZINE AND SHARON BILOTTA-BEST *Photo Researchers, Inc. (top);* MICHELLE DEL GUERCIO *Photo Researchers, Inc. (bottom)*

WWW.SCIAM.COM/NEWS

BRIEF BITS

- Confirming a long-suspected link, researchers have found that urban air pollution constricts blood vessels. The connection may explain why those with cardiovascular disease are at greater risk of heart attack in smoggy settings. /031202/2.html
- Biomechanically speaking, *Tyrannosaurus rex* was likely to have been a strolling behemoth rather than a fleet-footed sprinter. /022802/1.html
- Sound can make bubbles collapse violently enough to produce light (a process called sonoluminescence), but can such acoustic cavitation fuse nuclei? Much skepticism greeted a report of nuclear fusion in such a bubble system. /030602/1.html
- Implanted electrodes enabled rhesus monkeys to use their brains to move an onscreen cursor, bringing the possibility of controlling computers with the mind one step closer to reality. /031402/2.html

The Ultimate Clean Fuel

A start-up contemplates nonpolluting cars powered by an ingredient of soap By JULIE WAKEFIELD

EATONTOWN, N.J.—On a Saturday night, in a small garage near the Jersey shore, a mechanic turned on a Ford Explorer and put it into drive. The vehicle lunged two feet ahead. Sounds of jubilation erupted. Steven Amendola, a mustachioed chemist, jumped in the passenger seat. Five other giddy researchers piled in the back. They drove forward and backward, moving 10 feet at a time, again and again.

That joyride, possibly the world's shortest in distance, happened two years ago. Amendola's team had just proved that when dissolved in water an unassuming white powder made from borax, a common ingredient of laundry soap, could power a fuel-cell vehicle. No polluting emissions or greenhouse by-products would result from its combustion. Moreover, the basic fuel ingredient is relatively abundant.

HYDROGEN-ON-DEMAND vehicle undergoes inspection by Millennium Cell founder Steven Amendola (*left*) and company president and chief executive Stephen Tang.

Several months later the SUV helped to take public the fledgling company Millennium Cell, allowing it to raise $30 million. "We drove this one to the Nasdaq," quips program director Richard M. Mohring. Under the hood of the Ford Explorer is the brainchild of the Amendola-led team, the patented Hydrogen on Demand system, a compact series of pumps, tubes and catalyst chambers. When the fuel—a.k.a. sodium borohydride—contacts the catalyst, the reaction produces hydrogen gas, which, along with oxygen from air, drives most fuel cells. "We're the first to say that storing hydrogen is easy," Mohring observes. Hydrogen's volatility has been a critical hurdle to commercialization. But in the Millennium system, the hazard is reduced because the gas is produced onboard a small volume at a time and is kept at a mere fraction of the pressure of conventional compressed hydrogen supplies.

"In many regards, it's safer than gasoline," claims president and CEO Stephen Tang. The fuel itself, 7 percent hydrogen by weight, is nonflammable and nonexplosive. Another plus is that world reserves of borates, estimated at more than 600 million metric tons, could meet demand for decades, according to a recent study by U.S. Borax, a leading supplier. The known U.S. reserves rank second behind Turkey.

The energy density of sodium borohydride—the usable energy stored in each liter of hydrogen—brings fuel cells, with their hallmark high efficiency, within range of gasoline internal-combustion engines. The latest prototypes can power a fuel-cell vehicle for 300 miles before refueling. Last December, DaimlerChrysler unveiled the Natrium, a hybrid Town & Country concept minivan that uses a fuel-cell engine and a battery-assisted power train. In the Natrium, the Millennium technology gets its first test in a prototype vehicle, supplying hydrogen to a fuel cell made by Vancouver-based Ballard Power Systems. Now touring the country, the van ramps from zero to 60 mph in an unimpressive 16 seconds, although DaimlerChrysler is confident that better performance can be achieved.

The attractions of sodium borohydride's chemistry

PETER MURPHY

have been known for more than half a century. It was among the family of boranes developed as missile and jet propellants by both the U.S. and the former Soviet Union until new fuels came along in the 1950s. Today the compound is used mainly as a bleaching agent in paper mills. Working as an energy consultant in the early 1990s, Amendola grasped that sodium borohydride might be ideal for fueling the roomy gas guzzlers that Americans like to drive. A tinkerer since childhood who toyed with propellants and explosives in graduate school, he had secured two patents for cleaner coal processes before earning his Ph.D. in chemistry. With some spare sodium borohydride lying around his lab, Amendola fashioned a battery. Not only did it work on the first try, but it ran for 11 days straight. Attracting investors was easy.

To make those investments pay off, Millennium is calling on the brainpower and experience of two Nobel Prize–winning advisers and senior managers who defected from Duracell, Du Pont and Dow Chemical to bring the technology to the masses. The company must overcome a series of monumentally imposing technical barriers. Commercial sodium borohydride has a cost 50 times that of a comparable tank of gasoline. Moreover, the fuel supplies less energy than is required to produce it.

The lack of an infrastructure to provide a nonhydrocarbon energy source remains a serious stumbling block that the company alone cannot remove. Tang envisions the day when filling stations pump sodium borohydride into cars while a waste product, sodium borate, is pumped out and returned to a synthesis plant for recycling.

Millennium's fate will be tied to fuel-cell progress and broader societal factors that could eventually lead to the embrace of a nonhydrocarbon fuel. It is not just Millennium's fuel that is expensive. Savings afforded by technological advances and manufacturing economies of scale will be needed to bring the cost down for fuel cells. Yet Tang, a member of the U.S. Department of Energy's recently created Hydrogen Vision Panel, contends that forces are aligning to hasten the adoption of hydrogen technology, especially now that the Bush administration has ditched programs that advocate high-efficiency petroleum-fueled vehicles.

A series of interim technologies is needed while the company awaits the hydrogen economy. Internal-combustion engines that burn hydrogen supplied by the Millennium system instead of generating electricity with a fuel cell could be a stepping-stone to mass commercialization. Parked in the company's oversize garage is a New York City taxicab equipped with just such an engine. It emits low levels of nitrogen oxides compared with today's petroleum-burning engines and does not emit any carbon dioxide. Near-term applications for Millennium's technology may prove themselves for backup and portable power generators for a host of systems, including silicon chip factories, telecommunications networks, and "exoskeletons" (or strength-enhancing suits) for soldiers. Long-life sodium borohydride batteries and fuel-cell systems for the military could find their way into tanks, ships, unmanned air vehicles and more. Supply-chain advantages abound: marine vehicles, for example, could draw water from the ocean and mix it onboard with dry fuel to enable longer stints at sea before refueling.

To make its novel fuel into a commercial reality, Millennium Cell must overcome a series of monumentally imposing technical barriers.

Clean-car concepts come in many varieties, of course, including natural gas and methanol. A number of researchers predict that the ultimate answer will be a solid-state medium for hydrogen storage, perhaps using carbon nanotubes, a development still decades away. Whether Millennium emerges as more than a niche player hinges on its ability to line up the right partners early, according to David Sackler, vice president of Vestigo Associates, the research arm of Fidelity Capital Markets. So far the company has inked deals with U.S. Borax, Rohm and Haas, and Air Products and Chemicals on the supply side and is attracting various auto manufacturers on the demand front. Signing on a big energy company or automaker to build a large-scale production facility will be critical, Sackler says.

If Millennium can form the right alliances and bring down energy costs for more than a single Natrium car, its fuel technology could help usher in the new era, Tang predicts. If he gets his way, the white powder will power everything from small batteries for personal computers and wheelchairs to engines and large fuel cells in buses, ferries, submarines and perhaps even aircraft. All this musing brings a fresh buzz to a chemical whose prior fame stemmed from its association with Ronald Reagan's hawking of 20 Mule Team Borax cleanser on the television program *Death Valley Days*. SA

Julie Wakefield is a science and technology writer based in Washington, D.C.

IP Rights—and Wrongs

Does overstrong patent and copyright protection hamper competition? By GARY STIX

A fundamental tension exists between intellectual property and antitrust law. Intellectual property, or IP—in the form of patents and copyrights—can help a company build market power, whereas antitrust law tries to tear that power down when its misuse results in a stifling of competition.

In the 1960s and 1970s aggressive government antitrust policy discouraged patenting because of the assumption by regulators that the exclusive rights conferred by IP constituted market power that should be subject to antitrust scrutiny. Decades later Washington policymakers have now begun to ask whether this trend has moved too far in the opposite direction. Do overpowerful IP rights impede competitors from emerging in software and other technology markets? The Federal Trade Commission and the Department of Justice (DOJ) recently initiated hearings that, through June, will attempt to explore this question.

The hearings have focused debate on whether some patents are too broad in their coverage—thereby deterring innovation—and on whether a proliferation of patents affects competition. The U.S. Patent and Trademark Office (PTO) granted some 184,000 patents in 2001, more than two and a half times the number allowed in 1980. "The fact remains that there are more patent applications and more patents issued today per dollar of R&D than has been the case in many decades," said former FTC chairman Robert Pitofsky at the first FTC-DOJ hearing, held on February 6. "I don't think it's because we've become more original and more innovative."

The hearings are also probing the role of the Court of Appeals of the Federal Circuit (CAFC)—the court that hears appeals of patent cases, and that, according to some critics, has gone too far in strengthening IP rights. In 2000 the CAFC upheld a lower court ruling that Xerox had a right to refuse to sell its patented replacement parts and to license its copyrighted software to CSU, a leading copier repair company, even though in doing so the big manufacturer might quell competition in the copier service marketplace. The CAFC's opinion in *CSU v. Xerox* provides a demonstration of how "intellectual property has trumped antitrust," Pitofsky said at the first hearing.

Change is likely to proceed slowly: Charles James, the assistant attorney general for antitrust at the Department of Justice, said he was asked repeatedly before the hearings whether the government intended to revise the 1995 antitrust guidelines on IP, which were far less burdensome to patent and copyright holders than policies that prevailed through the 1970s. "Is this an effort to rewrite the intellectual-property guidelines?" James asked at the initial hearing. "I don't think that is necessarily where anyone is going here," he said, while adding, "We'll let the policy consequences of the information process select themselves out as we're more informed." And PTO director James E. Rogan noted at the same hearing that current FTC-DOJ guidelines encourage companies to realize the value of their patented technologies through licensing arrangements. "A return by [competition] regulators to viewing IP rights with a 1970s-era suspicion would risk interfering with these market-based incentives to innovate," Rogan said.

IP analysts welcomed the hearings because of the absence of high-level debate on these issues. Notes Josh Lerner, a Harvard University economist who testified at the hearings: "It's hard not to underestimate how difficult it has been to formulate policy in this area." SA

Please let us know about interesting and unusual patents. Send suggestions to: patents@sciam.com

JOHN McFAUL

Survival in an Insecure World

To defeat cyberterrorists, computer systems must be designed to work around sabotage. David A. Fisher's new programming language will help do just that By W. WAYT GIBBS

As one of the primary lines of defense against hackers, cyberterrorists and other online malefactors, the CERT Coordination Center at Carnegie Mellon University is a natural target. So like many high-profile organizations, it beefed up its security measures after September's audacious terrorist attacks. Before I can enter the glass and steel building, I have to state my business to an intercom and smile for the camera at the front door. Then I must sign my name in front of two uniformed guards and wait for an escort who can swipe her scan card through a reader (surveilled by another camera) to admit me to the "classified" area. But these barriers—just like the patting down I endured at the airport and like the series of passwords I must type to boot up my laptop—create more of an illusion of security than actual security. In an open society, after all, perfect security is an impossible dream.

STEVE MELLON

DAVID A. FISHER: PROGRAMMING PIONEER

- **Ten years ago, hiked the entire Appalachian Trail in 180 days.**
- **First job: programming multiprocessor mainframes in 1965 at Burroughs.**
- **"We'll never see another plane hijacked and crashed into a building, because passengers now will sacrifice themselves if necessary to thwart it. That's an example of an emergent algorithm that contributes to survivability."**

That is particularly true of computer systems, which are rapidly growing more complicated, interdependent, indispensable—and easier to hack. The tapestries of machines that control transportation, banking, the power grid and virtually anything connected to the Internet are all unbounded systems, observes CERT researcher David A. Fisher: "No one, not even the owner, has complete and precise knowledge of the topology or state of the system. Central control is nonexistent or ineffective."

Those characteristics frustrate computer scientists' attempts to figure out how well critical infrastructures will stand up under attack. "There is no formal understanding yet of unbounded systems," Fisher says, and that seems to bother him. In his 40-year career, Fisher has championed a rigorous approach to computing. He began studying computer science when it was still called mathematics, and he played a central role in the creation of Ada, an advanced computer language created in the 1970s by the Department of Defense to replace a babel of less disciplined programming dialects.

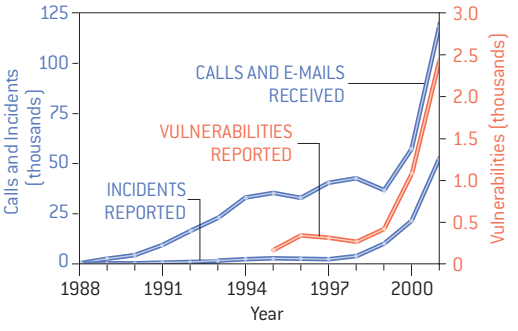
In the 1980s Fisher founded a start-up firm that sold software components, one of the first companies that tried to make "interchangeable parts" that could dramatically speed up the development process. In the early 1990s he led an effort by the National Institute of Standards and Technology (NIST) to push the software industry to work more like the computer hardware market, in which many competing firms make standard parts that can be combined into myriad products.

Fisher's quest to bring order to chaotic systems has often met resistance. The Pentagon instructed all its programmers to use Ada, but defense contractors balked. His start-up foundered for lack of venture capital. A

hostile Congress thwarted his advanced technology program at NIST. But by 1995, the year that Fisher joined CERT, security experts were beginning to realize, as CERT director Richard D. Pethia puts it, that "our traditional security techniques just won't hold up much longer."

The organization was founded as the Computer Emergency Response Team in 1988, after a Cornell University graduate student released a self-propagating worm that took down a sizable fraction of the Internet. There are now more than 100 such response teams worldwide; the CERT center at Carnegie Mellon helps to coordinate the global defense against what Pethia calls "high-impact incidents: attacks such as the recent Nimda and Code Red worms that touch hundreds of thousands of sites, attacks against the Internet infrastructure itself, and any other computer attacks that might threaten lives or compromise national defense."

But each year the number of incidents roughly doubles, the sophistication of attacks grows and the defenders fall a little further behind. So although CERT still scrambles its team of crack counterhackers in response to large-scale assaults, most of its funding (about half of it from the DOD) now goes to research.



CALLS TO CERT reporting new computer viruses, worms and hacker attacks—or new software flaws that allow bad guys to break in—have been doubling every year.

For Fisher, the most pressing question is how to design systems that, although they are unbounded and thus inherently insecure, have "survivability." That means that even if they are damaged, they will still manage to fulfill their central function—sometimes sacrificing components, if necessary. Researchers don't yet know how to build such resilient computer systems, but Fisher's group released a new programming language in February that may help considerably.

Fisher decided a new language was necessary when he started studying the mathematics of the cascade effects that dominate unbounded systems. A mouse click is passed to a modem that fillips a router that talks to a Web server that instructs a warehouse robot to fetch a book that is shipped out the same day. Or a tree branch takes down a power line, which overloads a transformer, which knocks out a substation, and within hours the lights go out in six states.

Engineers generally know what mission a system must perform. The power grid, for example, should keep delivering 110 volts at 60 hertz. "The question is: What simple rules should each node in the power grid follow to ensure that that happens despite equipment failures, natural disasters and deliberate attacks?" Fisher asks. He calls such rules "emergent algorithms" because amazingly sophisticated behavior (such as the construction of an anthill) can emerge from a simple program executed by lots of autonomous actors (such as thousands of ants).

Fisher and his colleagues realized that they could never accurately answer their question using conventional computer languages, "because they compel you to give complete and precise descriptions. But we don't have complete information about the power grid—or any unbounded system," Fisher points out. So they created a radically new programming language called Easel.

"Easel allows us to simulate unbounded systems even when given incomplete information about their state," Fisher says. "So I can write programs that help control the power grid or help prevent distributed denial of service attacks" such as those that knocked out the CNN and Yahoo! Web sites a few years ago.

Because it uses a different kind of logic than previous programming languages, Easel makes it easier to do abstract reasoning. "Computation has traditionally been a commerce in proper nouns: Fido, Spot, Rex," Fisher notes. "Easel is a commerce in common nouns: dog, not Fido." This difference flips programs upside down. In standard languages, a program would include only those attributes of dogs that the programmer judges are important. "The logic of the programming language then adds the assumption that all other properties of dogs are unimportant. That allows you to run any virtual experiment about dogs, but it also produces wrong answers," Fisher says. This is why computer models about the real world must always be tested against observations.

In Easel, Fisher says, "you enumerate only those properties of dogs about which you are certain. They have four legs, have two eyes, range from six inches high to four feet high. But you don't specify how the computer must represent any particular dog. This guarantees that the simulation will not produce a wrong answer. The trade-off is that sometimes the system will respond, 'I don't have enough information to answer that question.' "

Easel makes it easier to predict how a new cyberpathogen or software bug might cripple a system. CERT researcher Timothy J. Shimeall recently wrote a 250-line Easel program that models Internet attacks of the style of the Code Red worm, for example. That model could easily be added to another that simulates a large corporate network, to test strategies for stopping the worm from replicating.

Fisher and others have already begun using Easel to look for emergent algorithms that will improve the survivability of various critical infrastructures. "You can think of an adversary as a competing system with its own survival goals," Fisher says. "The way you win that war is not to build walls that interfere with your goals but to prevent the opposition from fulfilling its purpose." SA

SOURCE: CERT COORDINATION CENTER (WWW.CERT.ORG)

The Exquisite Balance

Science helps us understand the essential tension between orthodoxy and heresy in science By MICHAEL SHERMER

In a 1987 lecture entitled "The Burden of Skepticism," astronomer Carl Sagan succinctly summarized the delicate compromise between tradition and change:

> It seems to me what is called for is an exquisite balance between two conflicting needs: the most skeptical scrutiny of all hypotheses that are served up to us and at the same time a great openness to new ideas.... If you are only skeptical, then no new ideas make it through to you.... On the other hand, if you are open to the point of gullibility and have not an ounce of skeptical sense in you, then you cannot distinguish the useful ideas from the worthless ones.

Why, we might inquire, do some people prefer orthodoxy while others favor heresy? Is there a personality trait for preferring tradition and another for change? This is an important question because the answer helps to explain why in the history of science some chose to support radical new ideas while others opposed them.

Why do some people prefer orthodoxy while others favor heresy?

In 1990 David W. Swift published *SETI Pioneers: Scientists Talk about Their Search for Extraterrestrial Intelligence,* in which he identified an overabundance of firstborns, including Sagan. But is it a statistically significant overabundance? Swift, a sociologist at the University of Hawaii, did not compute this, but University of California at Berkeley psychologist Frank J. Sulloway and I did. Eight is the expected number of firstborns based on the number of siblings the SETI pioneers had, but 12 is the observed number. This difference is statistically significant at the 95 percent level of confidence.

So what? In Sulloway's book *Born to Rebel,* he presents a summary of 196 controlled birth-order findings classified according to the Five-Factor Model of Personality:

Conscientiousness. Firstborns are more responsible, achievement oriented, organized, and planful.

Agreeableness. Laterborns are more easygoing, cooperative, and popular.

Openness to Experience. Firstborns are more conforming, traditional, and closely identified with parents.

Extroversion. Firstborns are more extroverted, assertive, and likely to exhibit leadership.

Neuroticism. Firstborns are more jealous, anxious, neurotic, fearful, and likely to affiliate under stress.

To evaluate Sagan's personality, Sulloway and I requested a number of his friends to rate him on a standardized personality inventory of 40 descriptive adjectives using a nine-step scale between them. For example, I see Carl Sagan as someone who was: hardworking or lackadaisical, tough-minded or tender-minded, rebellious or conforming, et cetera.

The following results are in percentile rankings relative to Sulloway's database of more than 7,276 subjects.

Most consistent with his firstborn status was Sagan's exceptionally high ranking—88th percentile—on conscientiousness (ambitiousness, dutifulness) and his strikingly low ranking of the 13th percentile on agreeableness (tender-mindedness, modesty). But his openness to experience (preference for novelty) was nearly off the scale at the 97th percentile. Why? First, birth order is hardly the only influence on openness and can be affected by cultural influences and social attitudes—Sagan was raised in a socially liberal Jewish family, and he was mentored by such scientific revolutionaries as Joshua Lederberg and H. J. Muller. Second, openness also includes an "intellectual" component, and firstborns tend to excel at intellectual pursuits, as reflected by their higher I.Q. scores and a tendency to win more Nobel Prizes in science.

Here is the key to understanding the exquisite balance between tradition and change: Sagan's high openness led him to be a SETI pioneer, but his high conscientiousness made him skeptical of UFOs. Considering the example of Sagan, we can glean a valuable lesson on how science operates effectively in discriminating sense from nonsense, and it is science that helps us understand how and why this should be so. How recursive! SA

Michael Shermer is founding publisher of Skeptic *magazine (www.skeptic.com) and author of* The Borderlands of Science.

BRAD HINES

AUTOMOBILE NAVIGATION

Getting There

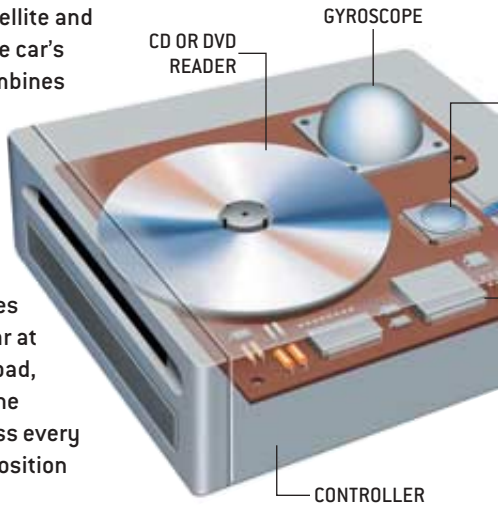
Dashboard navigation systems that display a map and give you directions are becoming increasingly popular. As you drive, a navigator's controller gathers information from Global Positioning System (GPS) satellites, the car's speedometer wire and its own gyroscope to pinpoint your location. It then references maps in its memory to place your car on a specific road. The controller updates position coordinates each second to track whether you've reached an intersection, for example, or turned the wrong way.

When you want directions, you use a remote control to enter a street address or select a prestored point of interest, such as a restaurant. Heuristic software explores all possible paths from the destination to your car's current position and calculates the fastest route based on information that describes the various road sizes, speed limits and so on. Now the tricky part. A synthesized voice tells you what your next move should be—for instance, "Make next right." But the navigator must announce the instruction at the appropriate time. You don't want to hear "Prepare to turn right" repeatedly for a whole minute, but you also don't want to hear "Turn right now!" with only a second remaining. The software uses algorithms to fit the ongoing motion data into map data to determine what instruction to give you and when.

The calculations are of no use if the maps are not accurate. Navigation Technologies in Chicago compiles the maps for all car navigators in the U.S. and most in Europe. For each new territory, it begins with a government base map but employs an army of field analysts who drive every foot of every road to correct it and add details. "The field guys are the real heart of our system," says Austin Klahn, vice president of technology development at NavTech. As an analyst drives along, a NavTech system tracks his position, and he enters into a connected laptop any of 150 physical features: stop signs, turn restrictions at intersections, curb cuts into parking lots, street addresses for every block. The laptops update NavTech's central database, which the company compresses onto a CD-ROM or DVD. Customers load the latest disc into their system and receive updates periodically by mail. *—Mark Fischetti*

IN-DASH DISPLAY
shows a road map of the car's surroundings. A synthesized voice tells the driver what the next highway exit or local turn should be in order to proceed toward a desired destination.

CONTROLLER
uses the time stamps to calculate the car's distance from each satellite and triangulates to determine the car's latitude and longitude. It combines this information with the vehicle's direction, sensed by a gyroscope and compass, and speed from the speedometer wire. It then compares the data against road-map coordinates in its memory to place the car at a single point on a specific road, accurate to within 15 feet. The controller repeats the process every second to update the car's position and velocity.



ILLUSTRATIONS BY GEORGE RETSECK

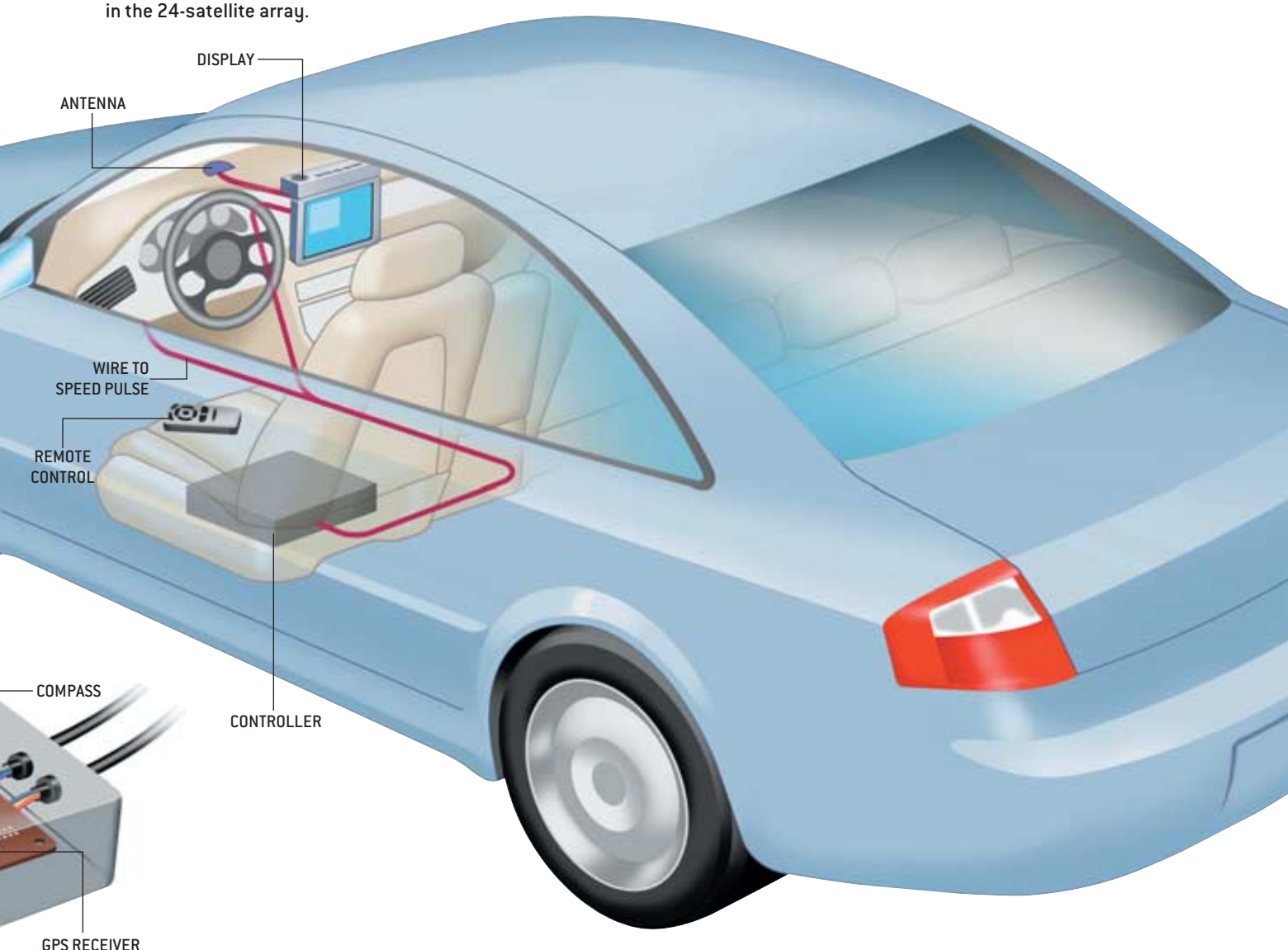
DID YOU KNOW . . .

➤ U.S. TRAILS About 15 to 20 percent of new car buyers in Japan order models with onboard navigation systems, compared with 5 to 10 percent in Europe and 2 percent in the U.S. The typical American system lists for $1,500 to $2,000. Prices are lower in Japan and Europe. Market research indicates that if prices drop below $500, many Americans would order a navigation system as an option on a new car.

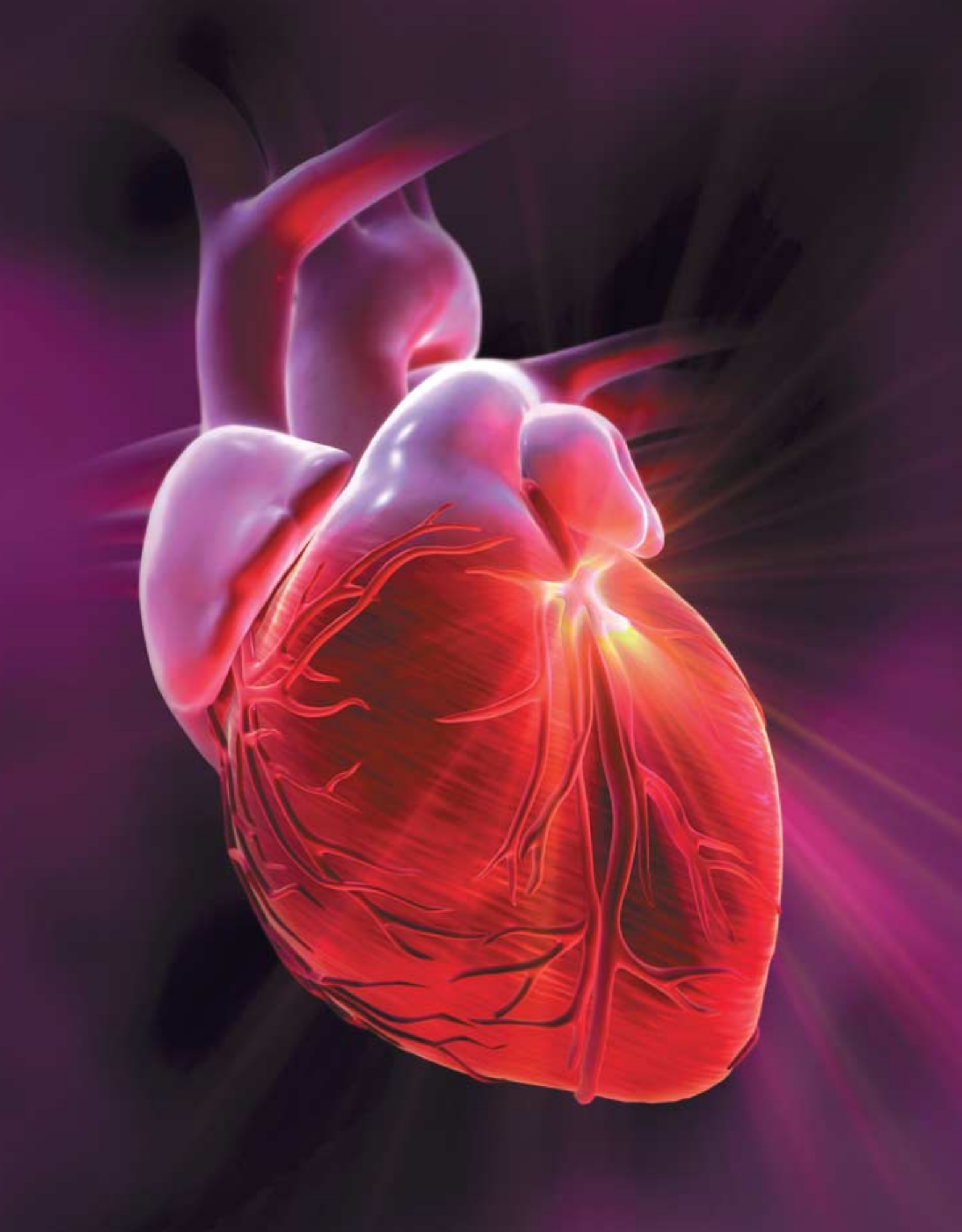
➤ NO PERFECT ROUTE Although Navigation Technologies creates the maps for U.S. navigators, manufacturers such as Delphi make the hardware installed by car companies. Automaker divisions, such as OnStar at General Motors, provide the services. "There is an optimal routing algorithm," NavTech's Austin Klahn says, "but it requires a lot of computing." A system could take 10 minutes to calculate the optimal route—too long for a driver. But a one-second calculation might give a terrible route. Each service provider devises its own algorithms to settle on the best directions possible in a timely manner, typically within 10 seconds.

➤ THE ROAD AHEAD If makers of handheld digital assistants can up their device memory to 500 megabytes or one gigabyte and add GPS gear, they could offer navigators as well. That way city dwellers, or visitors, could get walking or subway directions to restaurants and offices. The unit could also replace the in-dash part of a car navigator. Bernoulli and IBM are already offering one-gigabyte microdrives for handhelds.

ANTENNA
receives an exact time stamp from three or four GPS satellites in the 24-satellite array.



This month's topic was suggested by reader Ray O'Donnell. Have an idea for a future column? Send it to workingknowledge@sciam.com



ATHEROSCLEROSIS: THE NEW VIEW

It causes chest pain, heart attack and stroke, leading to more deaths every year than cancer. The long-held conception of how the disease develops turns out to be wrong

By Peter Libby

JEFF JOHNSON *Hybrid Medical Animation*

ATHEROSCLEROSIS in an artery feeding the heart can set the stage for a heart attack.

AS RECENTLY AS FIVE YEARS AGO, most physicians would have confidently described atherosclerosis as a straight plumbing problem: Fat-laden gunk gradually builds up on the surface of passive artery walls. If a deposit (plaque) grows large enough, it eventually closes off an affected "pipe," preventing blood from reaching its intended tissue. After a while the blood-starved tissue dies. When a part of the cardiac muscle or the brain succumbs, a heart attack or stroke occurs.

Few believe that tidy explanation anymore. Investigations begun more than 20 years ago have now demonstrated that arteries bear little resemblance to inanimate pipes. They contain living cells that communicate constantly with one another and their environment. These cells participate in the development and growth of atherosclerotic deposits, which arise in, not on, vessel walls. Further, relatively few of the deposits expand so much that they shrink the bloodstream to a pinpoint. Most heart attacks and many strokes stem instead from less obtrusive plaques that rupture suddenly, triggering the emergence of a blood clot, or thrombus, that blocks blood flow.

The research has, moreover, established a key role for inflammation in atherosclerosis. This process—the same one that causes infected cuts to become red, swollen, hot and painful—underlies all phases of the disorder, from the creation of plaques to their growth and rupture. When microbial invaders threaten to hurt us, inflammation (literally meaning "on fire") helps to ward off infection. In the case of atherosclerosis, though, the inflammation proves harmful. In other words, our own defenses bombard us with friendly fire, just as happens in more famously inflammatory conditions, such as rheumatoid arthritis.

This revised conception suggests new ideas for detecting and treating atherosclerosis. It also resolves some disturbing mysteries—notably, why many heart attacks strike without warning and why certain therapies meant to avert heart attacks frequently fail. Society sorely needs advances in prevention, detection and therapy of atherosclerosis. Contrary to public perception, the heart attacks and strokes that result from this condition exceed cancer as a cause of death in industrial nations and are growing more prevalent in developing countries as well.

Overview/*Atherosclerosis*

- Scientists now agree that inflammation fuels the development and progression of atherosclerosis: the dangerous accumulation of fat-laden deposits, or plaques, in the arteries. The old view—that fat builds up on passive artery walls—is no longer tenable.
- Inflammation can also cause certain plaques to rupture. Blood clots tend to form over ruptured plaques and can then occlude arteries, leading to such atherosclerotic complications as heart attack and stroke.
- Excess low-density lipoprotein (LDL), or "bad cholesterol," in the blood can trigger arterial inflammation. And cholesterol-lowering therapies—already cornerstones of treatment for atherosclerosis—can reduce it. Strategies that interfere with inflammation in other ways are under study as well.
- A blood test that detects ongoing inflammation might prove useful as an adjunct to the cholesterol tests that doctors now employ to assess risk for heart attack and stroke.

Igniting Trouble

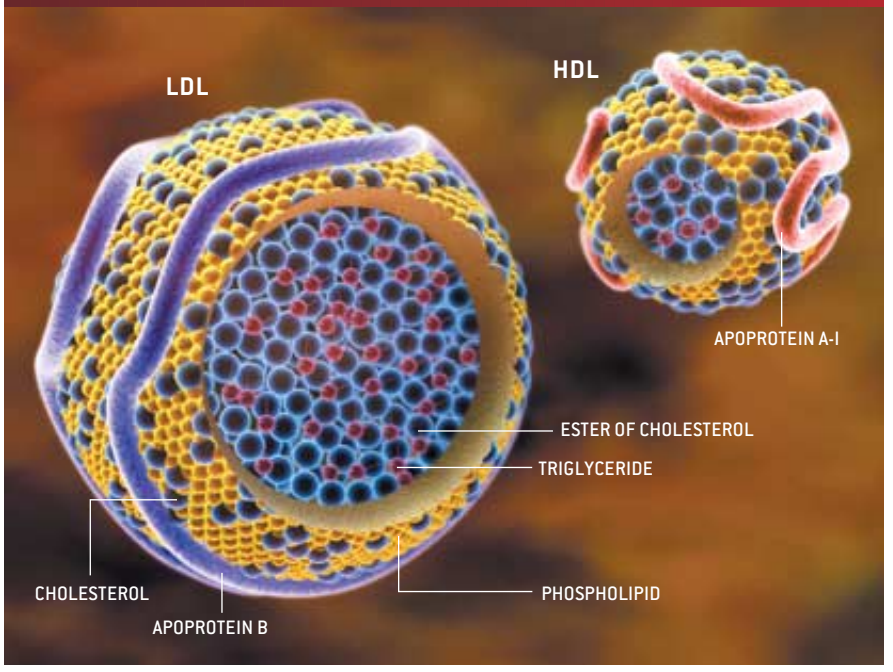
LACKING TOOLS to describe interactions among cells and molecules, the ancients who first defined inflammation had to focus on what they could see and feel. Today we know that the outward signs reflect a pitched struggle playing out on a microscopic battlefield. After sensing (rightly or wrongly) that a microbial attack has begun, certain white blood cells—the immune system's frontline warriors—convene in the apparently threatened tissue. There they secrete an array of chemicals intended to limit any infection. These chemicals include oxidants (able to dam-

NEW ROLES FOR FAMILIAR ACTORS

POPULAR DESCRIPTIONS of atherosclerosis correctly cast low-density lipoprotein (LDL) as "bad" and high-density lipoprotein (HDL) as "good." Yet these particles (*shown in cutaway views*) fulfill their roles in more ways than scientists once thought.

Lipoproteins transport cholesterol in the bloodstream. LDLs truck it from the liver and intestines to various tissues, which use it to repair membranes or produce steroids. HDLs haul cholesterol to the liver for excretion or recycling. The classic view of how atherosclerosis develops implies that excess LDL promotes the condition by accumulating on vessel walls. More recent work shows that it accumulates *within* vessel walls, where its components become oxidized and altered in other ways; the altered components then incite an inflammatory response that progressively—and dangerously—alters arteries.

Physicians also generally explain HDL's protective effects as deriving from its removal of cholesterol from arteries. HDL certainly does that, but new findings indicate it can also combat atherosclerosis by interfering with LDL oxidation. —*P.L.*



age invaders) and signaling molecules, such as small proteins called cytokines, that orchestrate the activities of defensive cells. Researchers therefore document an inflammatory response by identifying inflammatory cells or mediators of their activities in a tissue.

The clearest picture of inflammation's role in the onset of atherosclerosis comes from investigations into low-density lipoprotein, a.k.a. bad cholesterol. LDL particles, composed of fatty molecules (lipids) and protein, transport cholesterol (another lipid) from their source in the liver and intestines to other organs. Scientists have long known that although the body needs LDL and cholesterol, excessive amounts promote atherosclerosis. Until recently, however, no one could explain how a surplus leads to plaque formation.

Experiments on cultured cells and animals now indicate that the trouble begins when LDLs from the blood collect in the intima, the part of the arterial wall closest to the bloodstream [*see illustration on next two pages*]. At reasonable concentrations in the blood, LDLs can pass in and out of the intima, which consists mainly of the endothelial cells that line vessel walls, the underlying extracellular matrix (connective tissue), and a smattering of smooth muscle cells (matrix producers). But in excess, LDLs tend to become stuck in the matrix.

As the LDLs accumulate, their lipids undergo oxidation (similar to the processes that rust pipes and spoil butter) and their proteins undergo both oxidation and glycation (binding by sugars). Cells in the vessel wall seem to interpret the changes as a danger sign, and they call for reinforcements from the body's defense system.

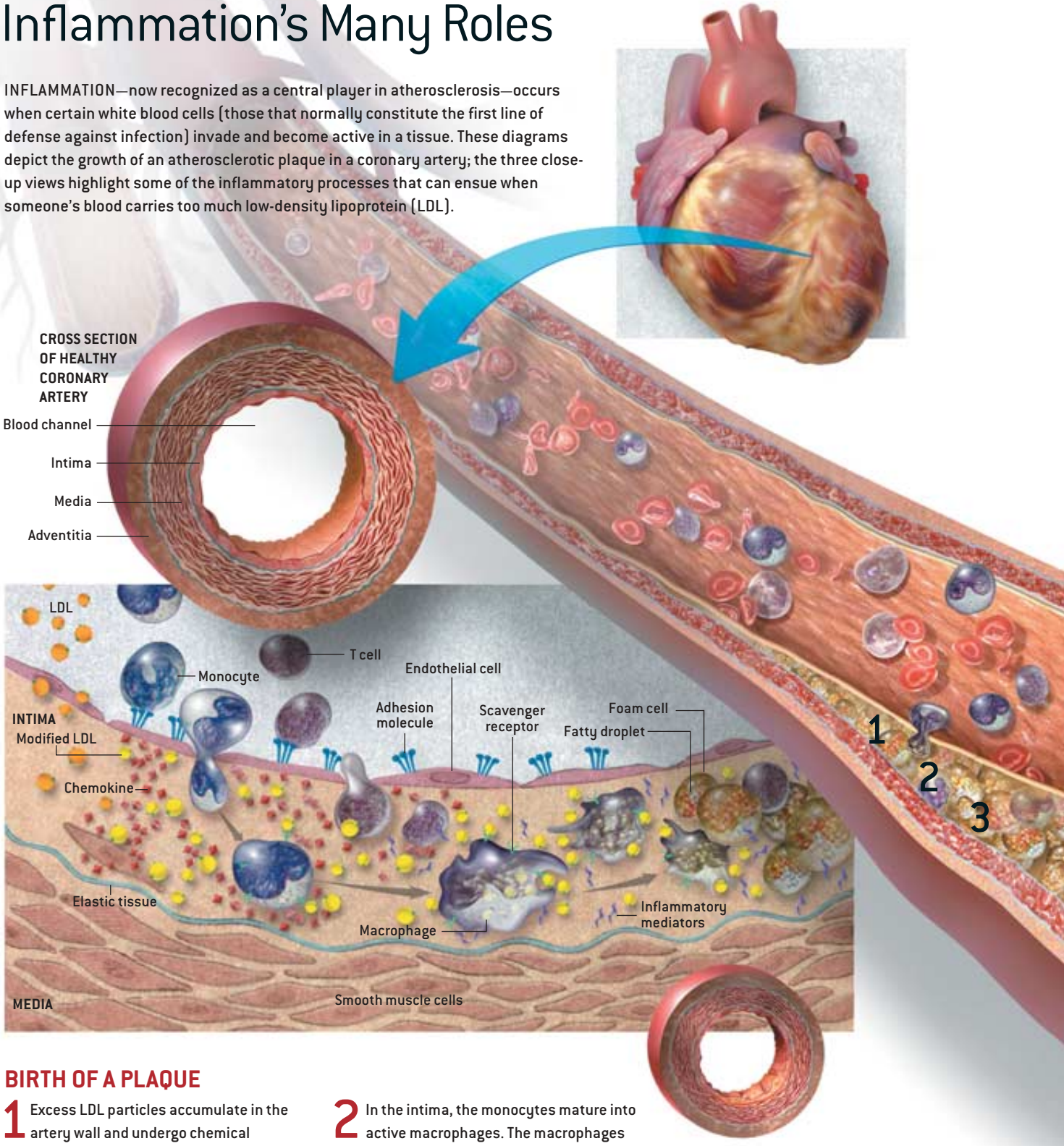
In particular, endothelial cells display adhesion molecules on their blood-facing surface. These molecules latch like Velcro onto quiescent inflammatory cells known as monocytes, which normally circulate in the blood. This interaction causes the cells to drop from the circulation and to roll along and attach to the artery wall. The modified LDLs also spur the endothelial cells and smooth muscle cells of the intima to secrete chemicals called chemokines, which attract monocytes. Much as hounds track the scent of their prey, the monocytes squeeze between endothelial cells and follow the chemical trail to the intima.

Chemokines and other substances elaborated by the endothelial and smooth muscle cells then induce the monocytes to multiply and mature into active macrophages: fully armed warriors, ready to unleash their various weapons against the body's enemies. These warriors also set about clearing perceived invaders from the vessel wall. Reacting to proteins emitted by stimulated endothelial and intimal smooth muscle cells, the macrophages decorate their surface with molecules called scavenger receptors, which capture modified LDL particles and help the macrophages ingest them. The macrophages ultimately become so packed with fatty droplets that they look foamy when viewed under a microscope. Indeed, pathologists refer to the fat-filled macrophages as foam cells.

Just as monocytes follow adhesion molecules and chemokines into the intima, so do T lymphocytes, white blood cells that represent a different branch of the immune system. These lymphocytes also release cytokines that amplify inflammatory activities in artery walls. Together the foamy macrophages and a lesser number of T lymphocytes compose the so-called fatty streak, a precursor of the

Inflammation's Many Roles

INFLAMMATION—now recognized as a central player in atherosclerosis—occurs when certain white blood cells (those that normally constitute the first line of defense against infection) invade and become active in a tissue. These diagrams depict the growth of an atherosclerotic plaque in a coronary artery; the three close-up views highlight some of the inflammatory processes that can ensue when someone's blood carries too much low-density lipoprotein (LDL).



BIRTH OF A PLAQUE

1 Excess LDL particles accumulate in the artery wall and undergo chemical alterations. The modified LDLs then stimulate endothelial cells to display adhesion molecules, which latch onto monocytes (central players in inflammation) and T cells (other immune system cells) in the blood. The endothelial cells also secrete "chemokines," which lure the snared cells into the intima.

2 In the intima, the monocytes mature into active macrophages. The macrophages and T cells produce many inflammatory mediators, including cytokines (best known for carrying signals between immune system cells) and factors that promote cell division. The macrophages also display so-called scavenger receptors, which help them ingest modified LDLs.

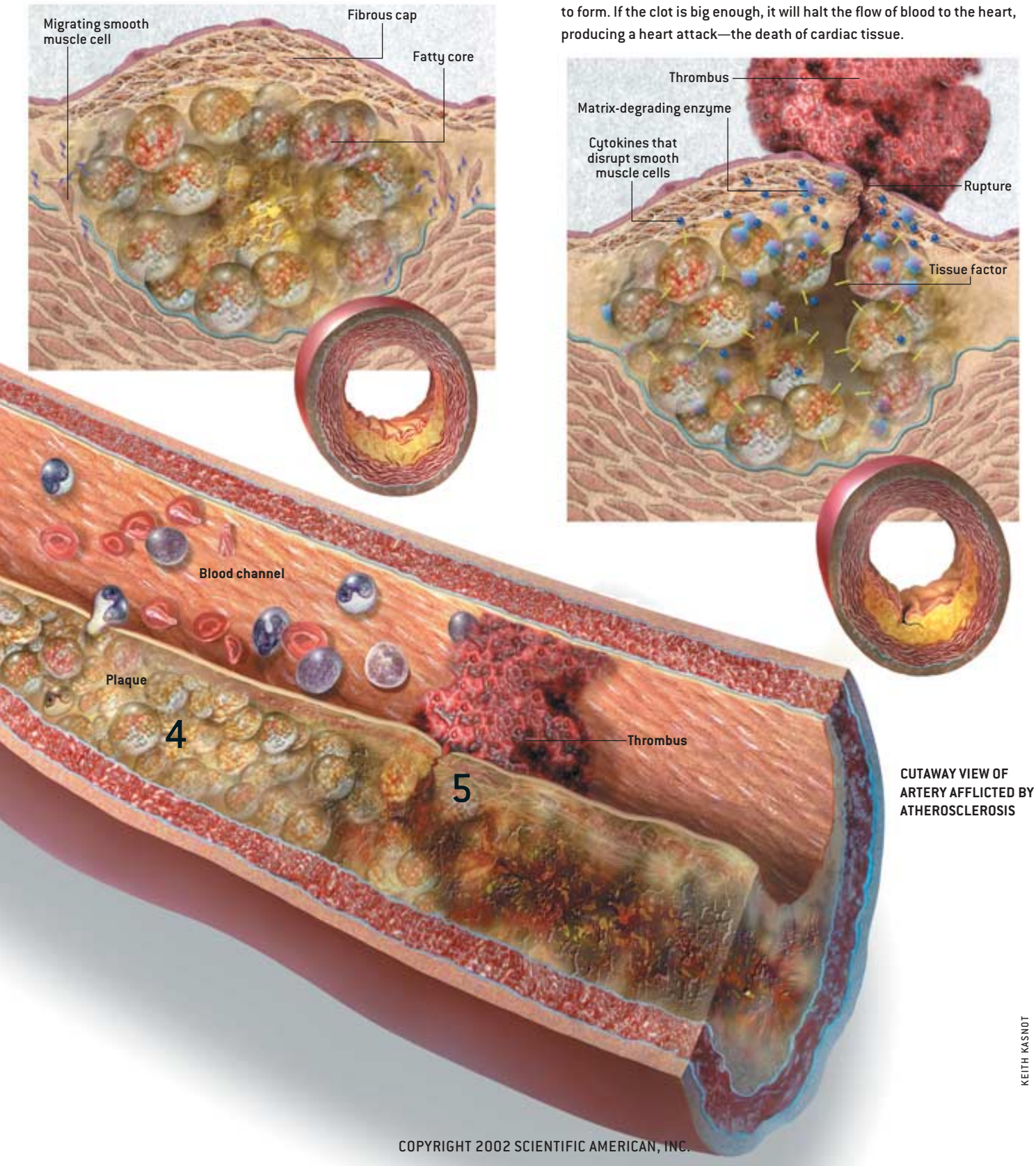
3 The macrophages feast on LDLs, becoming filled with fatty droplets. These frothy-looking, fat-laden macrophages (called foam cells) and the T cells constitute the fatty streak, the earliest form of atherosclerotic plaque.

PLAQUE PROGRESSION

4 Inflammatory molecules can promote further growth of the plaque and formation of a fibrous cap over the lipid core. The cap develops when the molecules induce smooth muscle cells of the media to migrate to the top of the intima, multiply and produce a tough, fibrous matrix that glues the cells together. The cap adds to the size of the plaque but also walls it off safely from the blood.

PLAQUE RUPTURE

5 Later, inflammatory substances secreted by foam cells can dangerously weaken the cap by digesting matrix molecules and damaging smooth muscle cells, which then fail to repair the cap. Meanwhile the foam cells may display tissue factor, a potent clot promoter. If the weakened plaque ruptures, tissue factor will interact with clot-promoting elements in the blood, causing a thrombus, or clot, to form. If the clot is big enough, it will halt the flow of blood to the heart, producing a heart attack—the death of cardiac tissue.



CUTAWAY VIEW OF ARTERY AFFLICTED BY ATHEROSCLEROSIS

KEITH KASNOT

complex plaques that later disfigure arteries. Disturbingly, many Americans harbor nascent plaques as early as their teens.

Fueling Plaque Growth

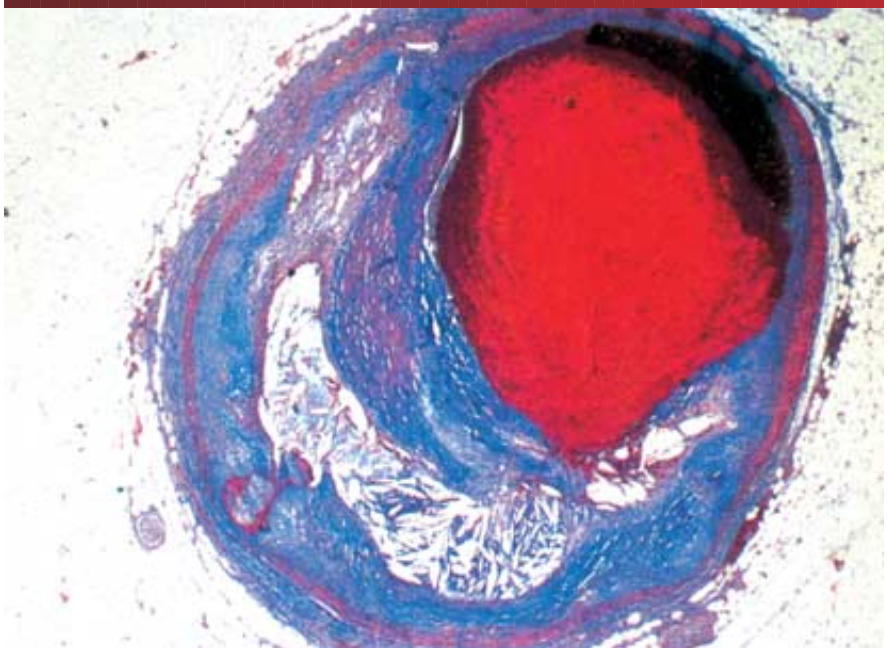
WHEN AN INFLAMMATORY response in, say, a scraped knee successfully blocks an infection, macrophages release molecules that facilitate healing. A "healing" process also accompanies the more chronic, low-level kind of inflammation that operates in atherosclerosis. Instead of restoring artery walls to their original state, though, the process perversely remodels—changes the character of—the wall, eventually generating a bigger, more complicated plaque.

In recent years, biologists have learned that macrophages, endothelial cells and smooth muscle cells of the inflamed intima secrete factors that prod smooth muscle cells of the media (the tissue under the intima) to migrate to the top of the intima, replicate and synthesize components of the extracellular matrix. The cells and matrix molecules coalesce into a fibrous covering overlying the original atherosclerotic zone. As this "cap" matures, the zone underneath generally changes somewhat. Most obviously, some fraction of the foam cells die, releasing lipids. For this reason, pathologists denote the region under the cap as the lipid or necrotic core.

Surprisingly, atherosclerotic plaques expand outward during much of their existence, rather than impinging on an artery's blood-carrying channel. This pattern preserves blood flow for quite some time, often for decades. When the plaques do push inward, they restrict the blood channel—a condition called stenosis. Stenosis can impede blood delivery to tissues, especially at moments of greater need, when the arteries would usually expand. When a person exercises or experiences stress, for instance, blood flow through a compromised heart artery can fail to match the increased demand, causing angina pectoris: a feeling of tightness, squeezing or pressure usually under the breastbone. Narrowing in other arteries can cause painful cramping of the calves or buttocks during exertion, symptoms known as intermittent claudication.

AN INSIDE VIEW

THE BLOOD CLOT, or thrombus (*red*), captured in this micrograph has formed at the site of an atherosclerotic plaque in a coronary artery and has occluded the vessel. Some clots dissolve before they cause a heart attack or stroke, but they can foster trouble in another way—by stimulating plaque expansion.



M. J. DAVIES/OXFORD UNIVERSITY PRESS/HARVEY MILLER PUBLISHERS

Causing Crises

SOMETIMES A PLAQUE grows so large that it virtually halts blood flow in an artery and generates a heart attack or stroke. Yet only about 15 percent of heart attacks happen in this way. By carefully examining vessel walls of people who died from heart attacks, pathologists have demonstrated that most attacks occur after a plaque's fibrous cap breaks open, prompting a blood clot to develop over the break. The plaques most likely to fracture possess a thinned cap, a large lipid pool and many macrophages, and their vulnerability stems, as in earlier stages of atherosclerosis, from inflammation.

The integrity of the fibrous covering depends largely on steel-strong collagen fibers made by smooth muscle cells. When something causes inflammation to flare in a relatively quiet plaque, mediators of the process can compromise the cap in at least two ways. My laboratory has shown that these inflammatory mediators can stimulate macrophages to secrete enzymes that degrade collagen, and they can inhibit smooth muscle cells from extruding the fresh collagen required to repair and maintain the cap.

Clots form when blood seeps through a fissure in the cap and encounters a lipid core teeming with proteins able to facilitate blood coagulation. For example, molecules on T cells in the plaques spur foam cells to manufacture high levels of tissue factor, a potent clot inducer. Circulating blood itself contains precursors of the proteins involved in the cascade of reactions responsible for clot formation. When blood meets tissue factor and other coagulation promoters in a plaque's core, the clotting precursors jump into action. Our bodies produce substances that can prevent a clot from materializing or can degrade it before it causes a heart attack or stroke, but inflamed plaques release chemicals that impede the innate clot-busting machinery.

If a clot does get cleared naturally or with the aid of drugs, the healing process may kick in once again, restoring the cap but also further enlarging the plaque by

forming scar tissue. Indeed, considerable evidence suggests that plaques grow in fits and starts, as triggers of inflammation come and go and as clots emerge and dissolve but leave scars.

The new picture of atherosclerosis explains why many heart attacks seem to come from out of the blue: the plaques that rupture do not necessarily protrude very far into the blood channel and so may not cause angina or appear prominently on images of the channel. The new view also clarifies why therapies that focus on widening the blood passage in semioccluded arteries (balloon angioplasty or insertion of wire-cage stents) or on surgically creating a bypass can ease angina yet frequently fail to prevent a future heart attack. In such cases, the danger may lurk elsewhere, where a plaque causes less narrowing but is more prone to rupturing. Sadly, even when stenosis *is* the problem, treated arteries often become reoccluded fairly rapidly—apparently in part because the treatments can elicit a robust inflammatory response.

Beyond Bad Cholesterol

ALTHOUGH LDL frequently sparks the sequence of events I have outlined, scientists have identified several other factors that unequivocally increase a person's risk for atherosclerosis or its complications. Many of these risk factors, and a few still under study, exhibit intriguing inflammatory properties. Before I describe some of those features, I must first point out that LDL probably plays an even larger role in initiating and perpetuating atherosclerosis than is generally recognized.

A much repeated statistic says that half of all patients who have angina or have had a heart attack do not have above-average LDL levels—a finding frequently interpreted to mean that in such individuals, LDL exerts no influence on the atherosclerosis at the root of those disorders. But typical LDL levels in Western society exceed by far the body's needs and can actually promote arterial disease.

Indeed, in response to new data correlating heart health with lipoprotein levels, public health experts have progressively refined the definition of "healthy" LDL levels. Guidelines released last year by an expert panel convened in cooperation with the National Institutes of Health now explicitly label LDL-cholesterol levels below 100 milligrams per deciliter of blood (mg/dL) as optimal. They also suggest considering drug treatment earlier than before—at 130 mg/dL instead of 160—for certain people with multiple risk factors. For adults with a relatively low risk of heart disease, the guidelines recommend (as before) initiating "lifestyle changes"—diet and exercise—at 160 mg/dL and considering drug treatment at 190 mg/dL.

Investigators have yet to explore the connections between other risk factors and inflammation with the intensity accorded to LDL, but they have uncovered suggestive links. Diabetes, for instance, elevates glucose levels in the blood; this sugar can enhance the glycation, and thus the inflammatory properties, of LDL. Smoking causes oxidants to form and might hasten the oxidation of LDL's constituents, thereby fostering arterial inflammation even in individuals with average LDL levels. Obesity contributes to diabetes and vascular inflammation. High blood pressure may not exert direct inflammatory effects, but a hormone partly responsible for much human hypertension—angiotensin II—appears to incite inflammation as well; elevated levels of this hormone, then, might give rise to hypertension and atherosclerosis simultaneously.

Conversely, high-density lipoprotein (HDL) seems beneficial; as levels of this "good cholesterol" decline, the likelihood of suffering a heart attack goes up. Accordingly, to fine-tune estimates of cardiovascular risk, many physicians today measure not only levels of LDL in the blood but also the level of HDL and the ratio of LDL (or LDL plus its various relatives) to HDL. HDL may achieve its beneficial effects in part by reducing inflammation: along with cholesterol, it can transport antioxidant enzymes able to break down oxidized lipids.

Given inflammation's usual responsibility in the body—blocking and eliminating infectious agents—biologists have naturally looked at whether arterial infections might contribute to inflammation in the arteries. Recent work suggests that atherosclerosis can develop in the absence of infection. Nevertheless, circumstantial evidence suggests that certain microorganisms, such as herpesviruses or the bacterium *Chlamydia pneumonia* (a frequent cause of respiratory infections), could well induce or aggravate atherosclerosis at times. *C. pneumonia,* for instance, appears in many atherosclerotic plaques, and its constituents can evoke inflammatory responses by macrophages and by vascular endothelial and smooth muscle cells.

Infections might also act from a distance, in what I call an echo effect. When the body fights infections, inflammatory mediators can escape into the blood and travel to distant sites. These substances can, in theory, stimulate the white cells in atherosclerotic plaques, thereby prompt-

The ancients who first **DEFINED INFLAMMATION** had to focus on what they could see and feel. Today we know that the outward signs reflect a pitched struggle playing out on a **MICROSCOPIC BATTLEFIELD**.

THE AUTHOR

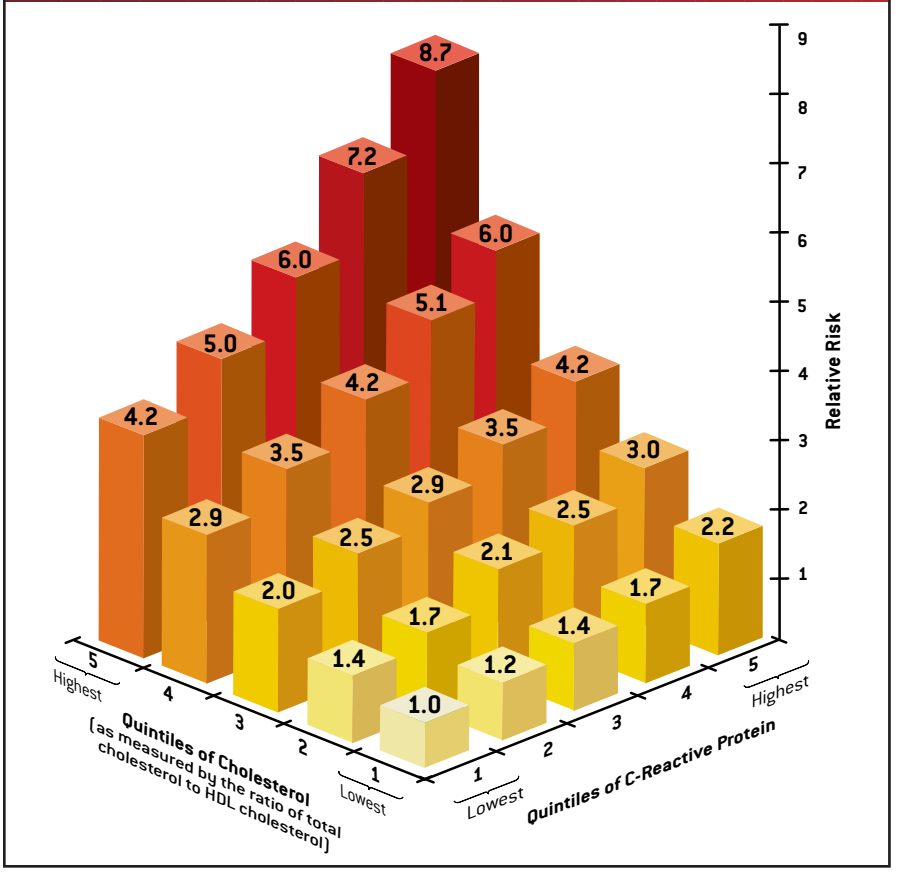
PETER LIBBY, who earned his M.D. from the University of California, San Diego, is chief of cardiovascular medicine at Brigham and Women's Hospital, Mallinckrodt Professor of Medicine at Harvard Medical School, and co-editor of the sixth edition of *Heart Disease,* a classic cardiology textbook (see "More to Explore," on page 55). He regards "lifestyle modification as the cornerstone of cardiovascular prevention" and practices what he preaches by running recreationally, albeit, he says, more avidly than swiftly.

A TELLING TEST

IN DECIDING WHETHER a patient requires therapy to prevent an atherosclerosis-related heart attack or stroke, physicians usually rely heavily on measurements of cholesterol in the person's blood. But that approach misses a great many vulnerable individuals. Several studies suggest that measuring blood concentrations of C-reactive protein—a marker of inflammation—could add useful information. Indeed, in one recent report, Paul M. Ridker of Brigham and Women's Hospital demonstrated that examining both C-reactive protein levels (which cannot be predicted from cholesterol measures) and cholesterol levels provides a more accurate indication of risk than assessing cholesterol alone (*graph*).

Ridker grouped cholesterol levels in the general adult population into five progressively rising ranges (quintiles) and, separately, divided C-reactive protein levels into quintiles as well. Then he determined the relative risk faced by people having different combinations of cholesterol and C-reactive protein values. That is, he assigned a danger level of "one" to individuals whose cholesterol and C-reactive values both fell in the lowest quintile (*front corner*) and calculated how much that risk multiplied in adults having other permutations of cholesterol and C-reactive protein measurements.

He found that high C-reactive protein values signify markedly elevated risk for heart attack or stroke even in individuals with seemingly reassuring cholesterol values. For instance, people with average (third-quintile) cholesterol levels and the highest C-reactive protein levels face much the same peril as those who have the highest cholesterol and lowest C-reactive protein levels. And subjects having the highest values for both cholesterol and C-reactive protein confronted the greatest risk of all. Encouraged by such results, researchers now hope to undertake a large study assessing whether basing treatment decisions on combined C-reactive protein and cholesterol testing will save lives. —*P.L.*



ing plaque growth or rupture. Clinical trials to see whether limited courses of antibiotics will prevent recurrent heart attacks are under way. A recently completed trial suggests, however, that antibiotics do not forestall recurrences in heart attack survivors.

Reducing Danger

INFLAMMATION'S essential role in atherosclerosis implies that anti-inflammatory medicines might slow this disease, and some (including aspirin) are already in use or under study. But logic and the investigations conducted so far suggest a need to look elsewhere as well.

Aspirin belongs to the class of drugs called NSAIDs (nonsteroidal anti-inflammatory drugs), a group that also claims such popular painkillers as ibuprofen and naproxen. Like other NSAIDs, aspirin can block the formation of certain lipid mediators of inflammation, including the prostaglandins, which generate pain and fever. Strong data from well-performed clinical trials indicate that aspirin shields against heart attacks and, in some patients, against mini strokes (technically, transient ischemic attacks, or TIAs). But the low doses that afford this protection probably reduce the clotting propensity of blood instead of quieting inflammation.

Scientists have little clinical data relating to the effects of other NSAIDs on atherosclerosis, and some evidence suggests that selective inhibitors of the prostaglandin-producing enzyme COX-2 might actually enhance thrombus development in some patients. Cortisone and related steroids could prove too toxic for long-term use, and no data support their utility in reducing atherosclerotic complications.

Even if anti-inflammatory drugs proved effective, they might have to be given for years on end to keep atherosclerosis at bay. That prospect worries me, because ongoing interference with inflammation could come at too high a price: increased risk of infection. One day someone could devise a way to halt the chronic, destructive inflammation of atherosclerosis without undermining overall immunity. But I suspect that a more practical strategy would concentrate on defusing the triggers at the root of arterial inflammation.

NINA FINKEL; SOURCE: "HIGH-SENSITIVITY C-REACTIVE PROTEIN: POTENTIAL ADJUNCT FOR GLOBAL RISK ASSESSMENT IN THE PRIMARY PREVENTION OF CARDIOVASCULAR DISEASE," BY PAUL M. RIDKER IN *CIRCULATION*, VOL. 103, PAGES 1813–1818, APRIL 3, 2001

Fortunately, some means are at hand already. A heart-healthy diet, regular exercise and, for obese individuals, weight loss can reduce the risk of a heart attack and combat diabetes. In addition, since 1994 several impeccably designed and executed clinical trials have established beyond a doubt that lipid-lowering drugs can reduce the likelihood of atherosclerotic complications and can prolong life seemingly across the board—that is, in individuals with a broad range of risk levels. Researchers have not yet nailed down the mechanism behind the success of the lipid-lowering drugs, which do not seem to reduce arterial stenosis substantially. But studies of cells, whole animals and humans suggest that lipid lowering (as might be expected from the foregoing discussion) might help by limiting inflammation, thereby minimizing plaque buildup and make existing plaques less likely to rupture.

Recent analyses of the statins (widely prescribed lipid-controlling drugs) support this notion. They confirm that the drugs can decrease inflammation in patients. Experiments on isolated cells and laboratory animals indicate as well that the drugs' anti-inflammatory effects may not depend entirely on changing the concentrations of lipids in the blood. Statins—which decrease the levels of LDL and related bad lipids by increasing their disposal in the body—also limit the availability of chemicals that enable cells to respond to inflammatory mediators.

Experimental drugs that aim at other risk factors for heart disease and stroke might exert useful anti-inflammatory effects as well. Agents that raise levels of HDL or limit the action of angiotensin II come to mind. But treatment with antioxidant vitamins has proved disappointing.

No matter how good a drug is, it will be of no value if it sits unused on pharmacy shelves. Doctors need better ways of detecting dangerous atherosclerosis in the large fraction of people whose lipid levels look too good to justify treatment. Recent findings suggest that blood tests combining lipid testing with monitoring of a substance called C-reactive protein might improve detection.

Toward Early Detection

THE PRESENCE of C-reactive protein in the blood signifies that inflammation is occurring somewhere in the body; highly elevated levels, even in the presence of LDL values too low to prompt treatment under current guidelines, indicate an increased risk of heart attack or stroke. What is more, in at least one study, delivery of statins to people with below-average LDL concentrations but high C-reactive protein levels reduced the incidence of heart attack relative to the rate in a matched group of patients who received no treatment. Such results need to be confirmed in a much larger trial before doctors can confidently treat patients on the basis of the combined test, although some physicians already incorporate tests of C-reactive protein in their practices.

Noninvasive methods for specifically identifying vulnerable plaques might also help pinpoint individuals who lack strong warning signs of risk for heart attack or stroke but who nonetheless are destined for disaster. Ideas include measuring the heat of blood vessels (because heat should accompany inflammation) and altering existing imaging technologies, such as MRI or CT scans, to improve their ability to visualize material inside vessel walls. Geneticists, meanwhile, hunt for gene variants that render some people more vulnerable to chronic inflammation and to atherosclerosis and its complications, so that individuals most prone to these disorders can seek more aggressive monitoring and treatment.

For most of human history, inflammation's ability to ward off infection outweighed its drawbacks. Today, as we live longer, exercise less, eat too much and smoke, many of us suffer from inflammation's dark side—including its ability to contribute to atherosclerosis and other chronic disorders. Scientists continue to pursue a deeper understanding of inflammation's role in atherosclerosis and to decipher the devilishly intricate interactions that ignite and drive the inflammatory processes in the arteries. These insights should enable us to make further inroads against a disease of growing worldwide importance that causes extensive disability and takes far too many lives. SA

THE NEW PICTURE of atherosclerosis explains why many heart attacks come from out of the blue: the plaques that rupture do not necessarily protrude very far into the blood channel and so **MAY NOT CAUSE ANGINA**.

MORE TO EXPLORE

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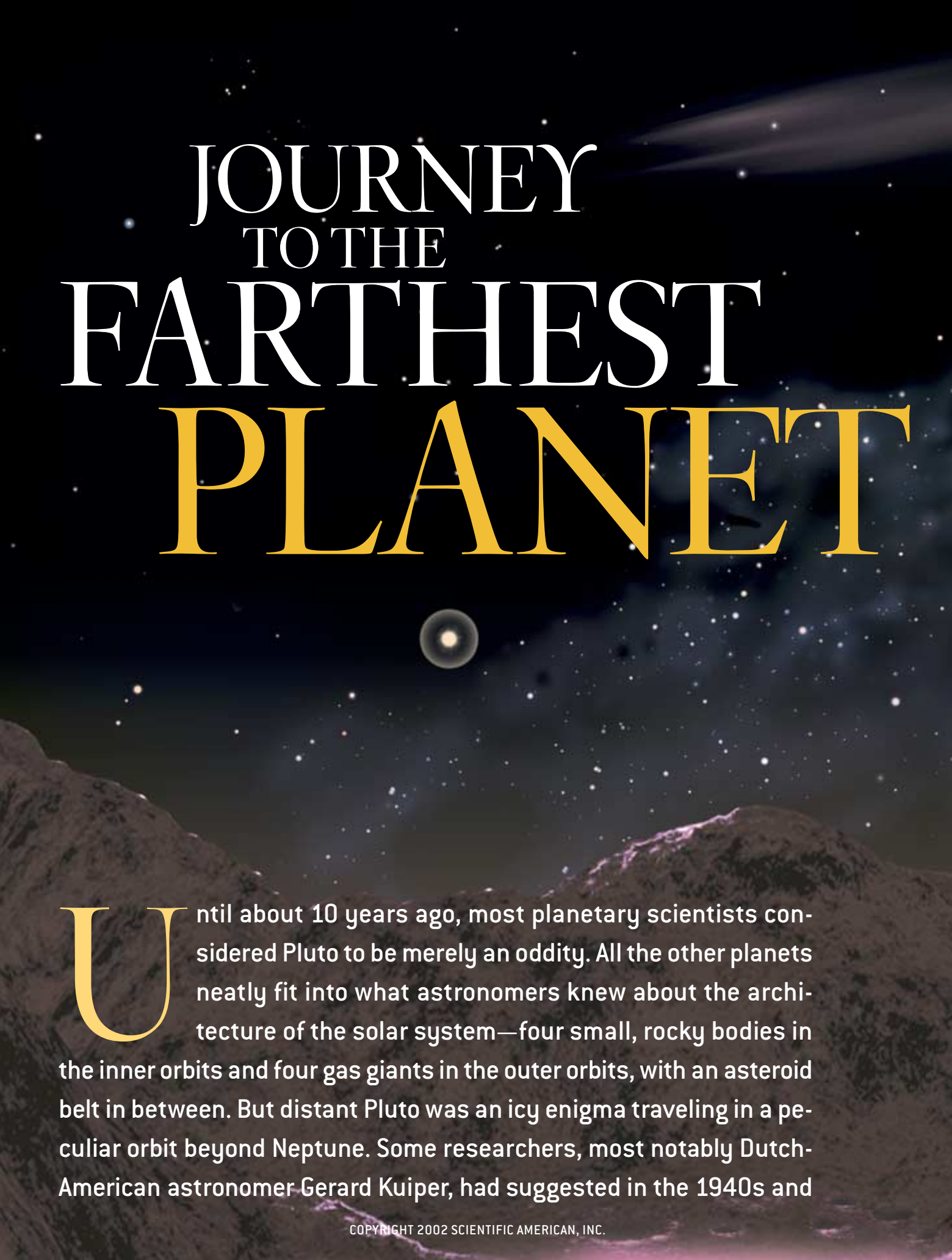
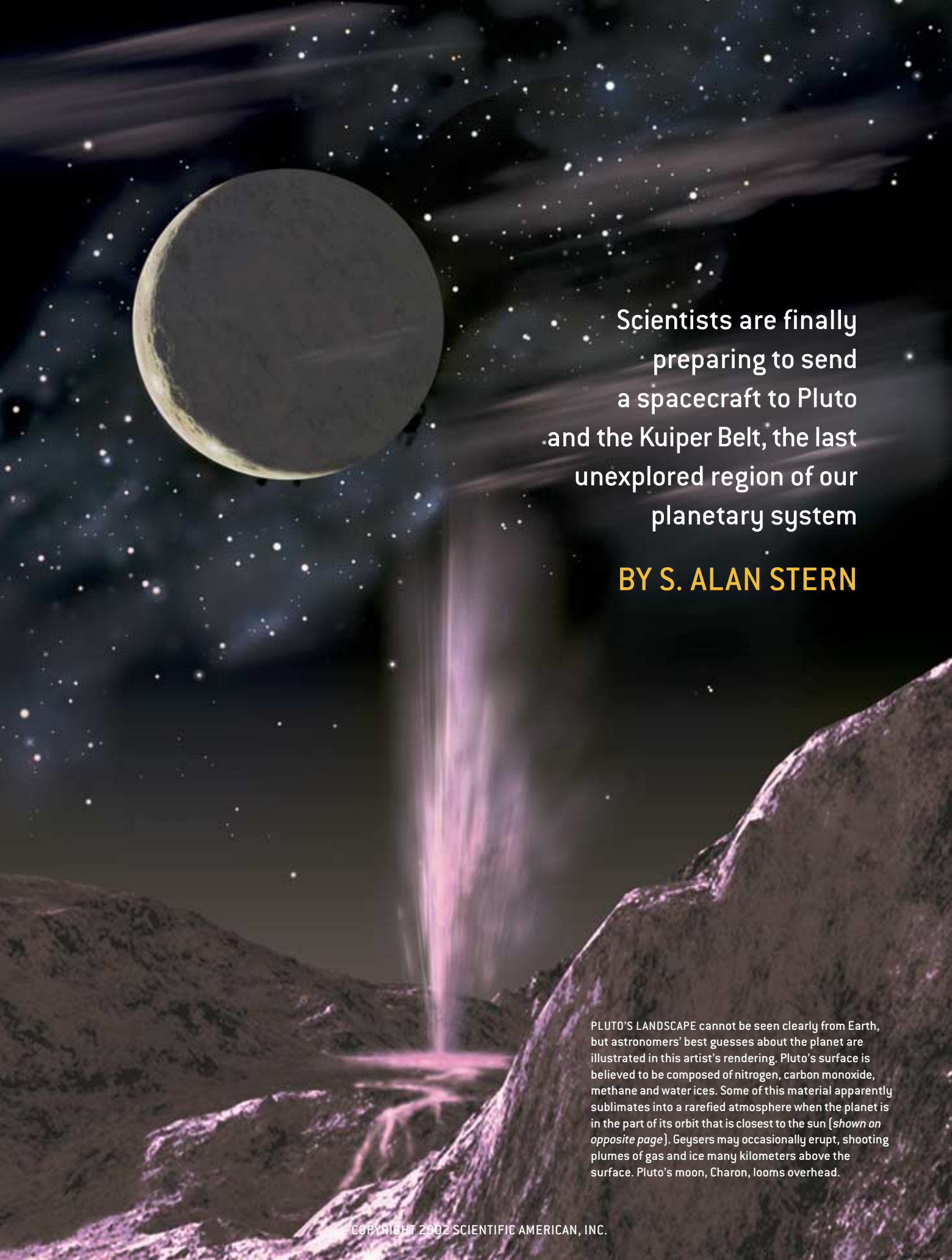


JOURNEY TO THE FARTHEST PLANET

Until about 10 years ago, most planetary scientists considered Pluto to be merely an oddity. All the other planets neatly fit into what astronomers knew about the architecture of the solar system—four small, rocky bodies in the inner orbits and four gas giants in the outer orbits, with an asteroid belt in between. But distant Pluto was an icy enigma traveling in a peculiar orbit beyond Neptune. Some researchers, most notably Dutch-American astronomer Gerard Kuiper, had suggested in the 1940s and



Scientists are finally preparing to send a spacecraft to Pluto and the Kuiper Belt, the last unexplored region of our planetary system

BY S. ALAN STERN

PLUTO'S LANDSCAPE cannot be seen clearly from Earth, but astronomers' best guesses about the planet are illustrated in this artist's rendering. Pluto's surface is believed to be composed of nitrogen, carbon monoxide, methane and water ices. Some of this material apparently sublimates into a rarefied atmosphere when the planet is in the part of its orbit that is closest to the sun (*shown on opposite page*). Geysers may occasionally erupt, shooting plumes of gas and ice many kilometers above the surface. Pluto's moon, Charon, looms overhead.

1950s that perhaps Pluto was not a world without context but the brightest of a vast ensemble of objects orbiting in the same region. This concept, which came to be known as the Kuiper Belt, rattled around in the scientific literature for decades. But repeated searches for this myriad population of frosty worlds came up empty-handed.

In the late 1980s, however, scientists determined that something like the Kuiper Belt was needed to explain why many short-period comets orbit so close to the plane of the solar system. This circumstantial evidence for a distant belt of bodies orbiting in the same region as Pluto drove observers back to their telescopes in search of faint, undiscovered objects beyond Neptune. By the 1980s telescopes were being equipped with electronic light detectors that made searches far more sensitive than work done previously with photographic plates. As a result, success would come their way.

In 1992 astronomers at the Mauna Kea Observatory in Hawaii discovered the first Kuiper Belt object (KBO), which was found to be about 10 times as small as and almost 10,000 times as faint as Pluto [see "The Kuiper Belt," by Jane X. Luu and David C. Jewitt; SCIENTIFIC AMERICAN, May 1996]. Since then, observers have found more than 600 KBOs, with diameters ranging from 50 to almost 1,200 kilometers. (Pluto's diameter is about 2,400 kilometers.)

And that's just the tip of the iceberg, so to speak. Extrapolating from the small fraction of the sky that has been surveyed so far, investigators estimate that the Kuiper Belt contains approximately 100,000 objects larger than 100 kilometers across. As a result, the Kuiper Belt has turned out to be the big brother to the asteroid belt, with far more mass, far more objects (especially of large sizes), and a greater supply of ancient, icy and organic material left over from the birth of the solar system.

It is now clear that Pluto is not an anomaly. Instead it lies within a vast swarm of smaller bodies orbiting between about five billion and at least eight billion kilometers from the sun. Because this far-off region may hold important clues to the early development of the solar system, astronomers are keenly interested in learning more about Pluto, its moon, Charon, and the bodies making up the Kuiper Belt. Unfortunately, the immense distance between this region of the solar system and Earth has limited the quality of observations. Even the exquisite Hubble Space Telescope, for example, shows only blurry regions of light and dark on Pluto's surface. And although the Pioneer, Voyager and Galileo spacecraft have provided scientists with marvelous close-up images of Jupiter, Saturn, Uranus and Neptune, no space probe has ever visited the Pluto-Charon system or the Kuiper Belt.

Recognizing the importance of this region of the solar system, scientists have urged NASA to put Pluto on its planetary exploration agenda for more than a decade. In response, the space agency has studied mission concepts ranging from houseboat-size, instrument-laden spacecraft similar to the Cassini probe (now on its way to Saturn) to hamster-size craft carrying just a camera. In the late 1990s NASA settled on a midsize concept called Pluto-Kuiper Express that would be built by the Jet Propulsion Laboratory in Pasadena, Calif. But the projected cost of that mission quickly rose toward $800 million, which was considerably more than NASA wanted to invest. As a result, the agency scrapped Pluto-Kuiper Express in the fall of 2000.

But this cancellation didn't go down easily. Scientists, space exploration advocates and schoolchildren flooded NASA with requests to reconsider, and the agency did so, but with a twist. Rather than restarting the expensive Pluto-Kuiper Express, NASA launched a competition among universities, research labs and aerospace companies for proposals to explore Pluto, Charon and the Kuiper Belt at lower cost. Never before had NASA allowed industry and universities to compete to lead a mission to the outer solar system. Given the novelty of such a competition, NASA made it clear that if none of the proposals could accomplish the specified scientific measurement objectives by 2020, and for less than $500 million, then the agency was under no obligation to choose *any* of them.

Last November, after a grueling selection process, NASA picked our team, called New Horizons, to carry out the Pluto–Kuiper Belt mission. New Horizons is led by my institution, the Southwest Research Institute, based in San Antonio, Tex., and the Applied Physics Laboratory (APL) at Johns Hopkins University. A team of scientists from more than a dozen universities, research institutions and NASA centers is deeply involved in planning the scientific observations. The Southwest Research Institute will manage the project, be in charge of the mission team and be responsible for the development of the scientific instruments. APL will build and operate the New Horizons spacecraft. Ball Aerospace, the NASA Goddard Space Flight Center and Stanford University will build portions of the instrument payload, and JPL will be responsible for spacecraft tracking and navigation.

By pioneering less expensive ways to build and operate a spacecraft to explore the outer solar system, New Horizons sat-

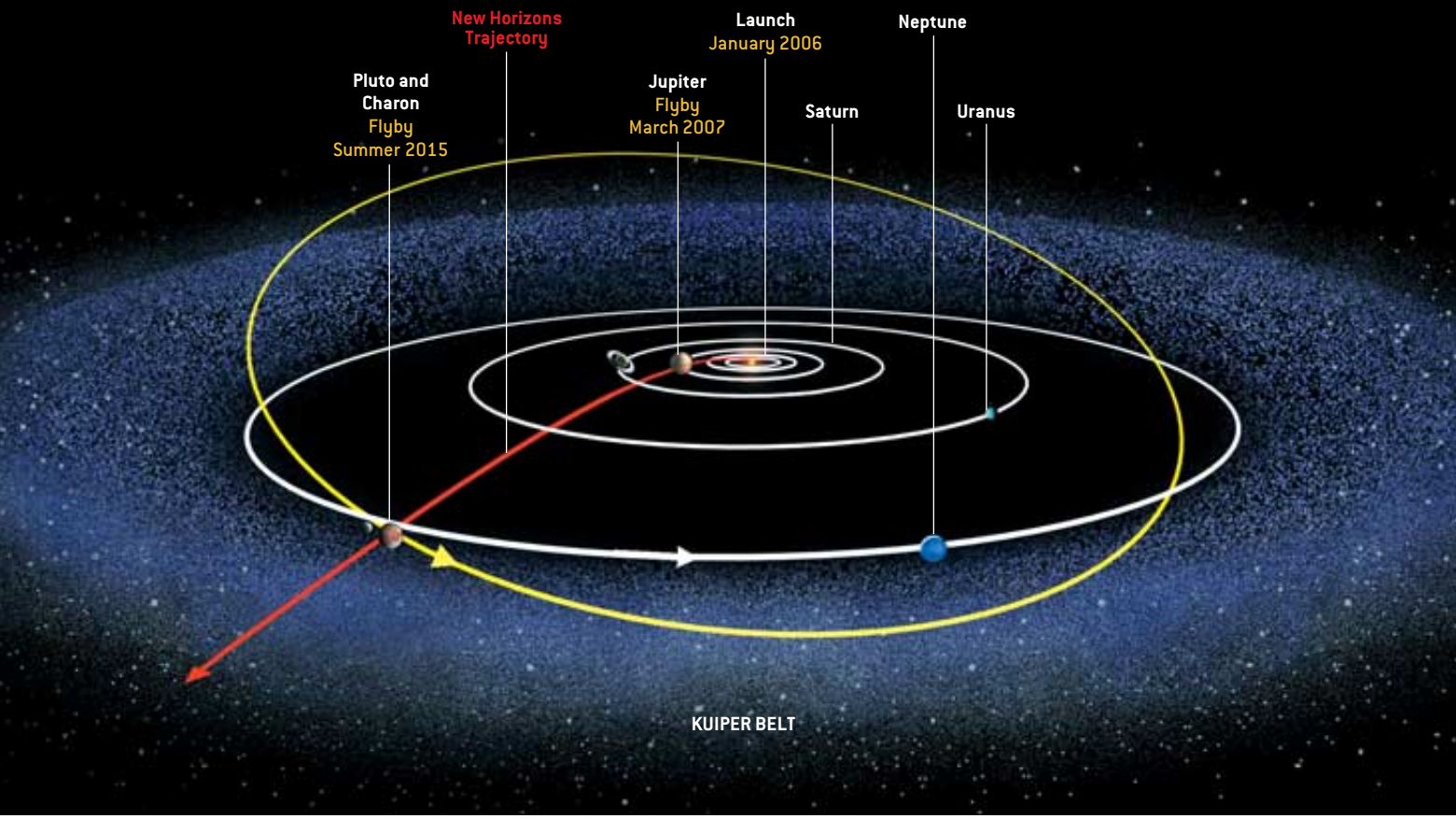
Overview/*New Horizons*

- Astronomers have recently learned that Pluto is not an anomaly, as once believed, but the brightest of a vast ensemble of objects orbiting in a distant region called the Kuiper Belt. Scientists want to explore Pluto and the Kuiper Belt objects because they may hold clues to the early history of the planets.
- Pluto and its moon, Charon, are also intriguing in their own right. The two bodies are so close in size that astronomers consider them a double planet. In addition, Pluto has a rapidly escaping atmosphere and complex seasonal patterns.
- NASA has chosen a team called New Horizons to build a spacecraft that would study Pluto, Charon and several Kuiper Belt objects during a series of flyby encounters. If its funding is approved by Congress, the spacecraft could be launched in 2006 and arrive at Pluto as early as 2015.

EDWIN FAUGHN [*preceding pages*]

OUTWARD BOUND

THE JOURNEY TO PLUTO could take less than 10 years if the New Horizons spacecraft is launched in 2006. Traveling along the planned trajectory (*red line*), New Horizons would head initially for a Jupiter flyby that would use the planet's gravity to slingshot the craft toward Pluto (*yellow orbit*). After investigating Jupiter in 2007 and the Pluto-Charon system in 2015, the probe would go on to reconnoiter several of the icy bodies in the Kuiper Belt.



DON DIXON

isfied NASA's conditions: the total mission cost is $488 million, including more than $80 million in budgeted reserves, and the spacecraft may arrive at Pluto as early as the summer of 2015. Furthermore, New Horizons would fly more instruments and return about 10 times as much observational data as the canceled Pluto-Kuiper Express mission would have delivered and would do so for less money.

The launch of New Horizons, however, is not yet a sure thing: in February, President George W. Bush removed the $122 million needed for the mission from NASA's budget for the 2003 fiscal year. But my colleagues and I are hopeful that Congress, which mandated NASA to select and begin the mission to Pluto and the Kuiper Belt, will reinstate funding for the construction of the craft. If so, New Horizons would be much more than the first mission to Pluto. During its journey, the spacecraft would also fly by and study Jupiter and its moons, and after flying by Pluto-Charon, the probe would go on to reconnoiter several KBOs at close range.

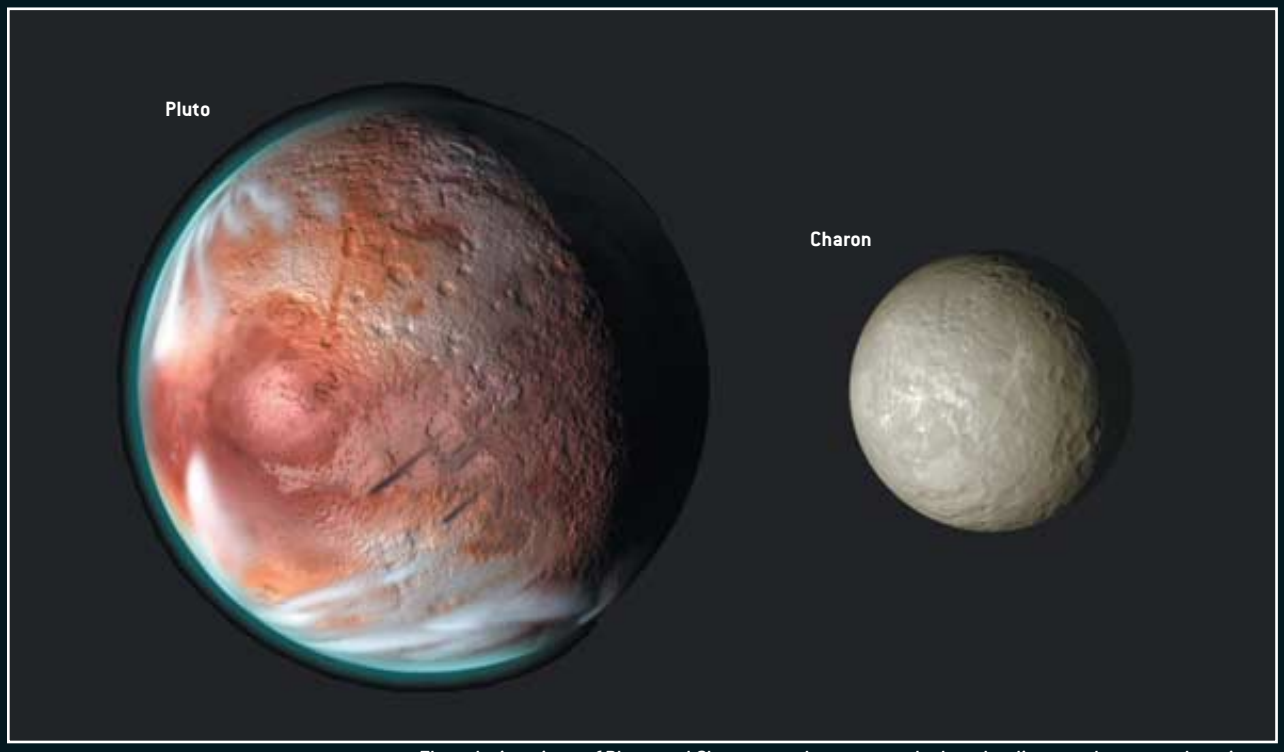
An Archaeological Dig in Space

WHY ARE ASTRONOMERS so interested in studying Pluto-Charon and the Kuiper Belt? I can summarize only a few of the reasons here. For one, the size, shape, mass and general nature of the Kuiper Belt appear to be much like the debris belts seen around other nearby stars, such as Vega and Fomalhaut. Researchers, including myself, have used computer modeling techniques to simulate the formation of the KBOs almost five billion years ago as the planetary system was coalescing from a whirling disk of gas and dust. We found that the ancient Kuiper Belt must have been approximately 100 times as massive as it is today to give rise to Pluto-Charon and the KBOs we see. In other words, there was once enough solid material to have formed another planet the size of Uranus or Neptune in the Kuiper Belt.

The same simulations also revealed that large planets like Neptune would have naturally grown from the KBOs in a very short time had nothing disturbed the

DISTANT WORLDS

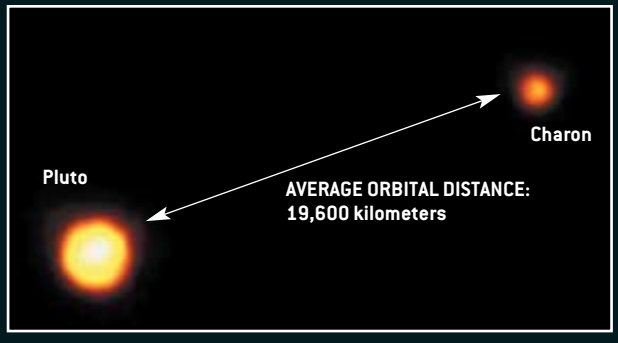
ASTRONOMERS ARE VERY INTERESTED in obtaining close-up views of Pluto and its moon, Charon, depicted here in an artist's rendering (*top*) based on the current knowledge of the two bodies. Because the Pluto-Charon system is so far from Earth, even the Hubble Space Telescope shows only blurry images of the two bodies (*bottom*).



The relative sizes of Pluto and Charon are drawn to scale, but the distance between them is not.

KEY FACTS

Diameter of Pluto: 2,400 kilometers
Diameter of Charon: 1,200 kilometers
Average distance of Pluto-Charon from sun: 5.9 billion kilometers
Orbital period around sun: 248 years
Average distance between Pluto and Charon: 19,600 kilometers
Orbital period of Charon around Pluto: 6.39 days
Rotation periods of Pluto and Charon: 6.39 days
Surface composition of Pluto: Nitrogen, carbon monoxide, methane and water ices
Surface composition of Charon: Water ice and possibly other compounds



region. Clearly, something disrupted the Kuiper Belt at about the time Pluto was formed, but we do not yet know the cause of the disturbance. Perhaps it was the formation of Neptune near the belt's inner boundary. Did the planet's gravitational influence somehow interrupt the creation of another gas giant farther out? And if so, why didn't the formation of Uranus frustrate the birth of Neptune in the same way? Perhaps instead it was the gravitational influence of a large population of planetary embryos—rocky bodies thousands of kilometers across—moving rapidly through the Kuiper Belt billions of years ago after they were ejected by Uranus and Neptune from their formation zones. Or perhaps it was something else altogether. Whatever the cause, the Kuiper Belt lost most of its mass, and the growth of bodies in the region was suddenly arrested.

The KBOs are remnants of that ancient planet-building process and therefore hold extremely important clues to the formation of the outer solar system. Exploring Pluto and the Kuiper Belt is the equivalent of conducting an archaeological dig into the history of the outer solar system—a place where researchers can get a valuable glimpse of the long-gone era of planetary formation.

Furthermore, although our knowl-

DON DIXON (*artist's rendering*); NASA/ESA/ESO (*Hubble image*)

edge of Pluto and Charon is meager, what we do know indicates that they offer a scientific wonderland of their own. For one, Charon is surprisingly large—its diameter is about 1,200 kilometers, or about half of Pluto's. Because the two bodies are so close in size, Pluto-Charon can be considered a double planet. No other planet in our solar system falls into this category—the diameters of most satellites are just a few percent of the diameters of their parent planets. But because astronomers have discovered many double asteroids and double KBOs in recent years, there is now little doubt that binary objects like Pluto-Charon are common in our solar system and most likely in others. Yet we have never visited a binary world.

We are eager to know how a system such as Pluto-Charon could form. The prevailing theory is that Pluto collided with another large body in the distant past and that much of the debris from this impact went into orbit around Pluto and eventually coalesced to form Charon. Because it appears that a similar collision led to the creation of Earth's moon, the study of Pluto and Charon is expected to shed some light on that subject as well.

Researchers also want to know why Pluto and Charon are so different in appearance. Observations from Earth and the Hubble Space Telescope show that Pluto has a highly reflective surface with distinct markings that indicate the presence of expansive polar caps. In contrast, Charon's surface is far less reflective, with indistinct markings. And whereas Pluto has an atmosphere, Charon apparently does not. Is the sharp dichotomy between these two neighboring worlds a result of divergent evolution, perhaps because of their different sizes and compositions, or is it a consequence of how they originally formed? We do not know.

Also intriguing is the fact that Pluto's density, size and surface composition are strikingly similar to those of Neptune's largest satellite, Triton. One of the great surprises of Voyager 2's exploration of the Neptune system was the discovery of ongoing, vigorous volcanic activity on Triton. Will Pluto also display such activity? Will the KBOs as well? Our present-day knowledge of planetary processes suggests that they should not, but Triton's activity was not expected either. Perhaps Triton is showing us that we do not yet understand the nature of small worlds. By exploring Pluto and the KBOs, we expect to gain a better comprehension of this fascinating class of bodies.

Yet another of Pluto's alluring features is its bizarre atmosphere. Although Pluto's atmosphere is about 30,000 times less dense than Earth's, it offers some unique insights into the workings of planetary atmospheres. Whereas Earth's atmosphere contains only one gas (water vapor) that regularly undergoes phase transitions between solid and gaseous states, Pluto's atmosphere contains three: nitrogen, carbon monoxide and methane. Furthermore, the current temperature on Pluto varies by about 50 percent across its surface—from about 40 to about 60 kelvins. Pluto reached its closest approach to the sun in 1989. As the planet moves farther away, most astronomers believe that the average surface temperature will drop and that most of the atmosphere will condense and fall as snow. Pluto may well have the most dramatic seasonal patterns of any planet in the solar system.

What is more, Pluto's atmosphere bleeds into space at a rate much like a comet's. Most of the molecules in the upper atmosphere have enough thermal energy to escape the planet's gravity; this extremely fast leakage is called hydrodynamic escape. Although this phenomenon is not seen on any other planet today, it may have been responsible for the rapid loss of hydrogen from Earth's atmosphere early in our planet's history. In this way, hydrodynamic escape may have helped make Earth suitable for life. Pluto is now the only planet in the solar system where this process can be studied.

An important connection between Pluto and the origin of life on Earth is the presence of organic compounds, such as frozen methane, on Pluto's surface and water ice in its interior. Recent observations of KBOs show that they, too, probably harbor large quantities of ice and organics. Billions of years ago such objects are believed to have routinely strayed into the inner part of the solar system and helped to seed the young Earth with the raw materials of life.

A Grand Tour Indeed

GIVEN SO MANY compelling scientific motivations, it is not hard to understand why the planetary research community wants to send a spacecraft to Pluto and the Kuiper Belt. And given the romance and adventure of exploring uncharted worlds, it is not surprising that so many citizens and grade school children have also become excited about this mission to new frontiers.

NASA's request for Pluto–Kuiper Belt mission proposals specified three top priorities for scientific observations. First, the craft must map the surfaces of Pluto and Charon with an average resolution of one kilometer (in contrast, the Hubble Space Telescope cannot do better than about 500-kilometer resolution when it views Pluto and Charon). Second, the probe must map the surface composition across the various geologic provinces of the two bodies. Third, the craft must determine the composition and structure of Pluto's atmosphere, as well as its escape rate. NASA also outlined a list of lower priorities, including the measurement of surface temperatures and the search for additional satellites or rings around Pluto. The agency also required that the spacecraft accomplish the same objectives for at least one KBO beyond Pluto.

When NASA selected our proposal late last year, it stated that the New Horizons mission offered both the best scientific return and the lowest risk of schedule delays and cost overruns. This was, in part, because of the robust capabilities of the spacecraft we proposed and the ex-

THE AUTHOR

S. ALAN STERN is a planetary scientist and the principal investigator of NASA's New Horizons mission to Pluto and the Kuiper Belt. He has participated in and led numerous space experiments and flies aboard NASA F-18s and other high-performance aircraft to conduct high-altitude airborne astronomical research. Stern received his Ph.D. in planetary science and astrophysics from the University of Colorado in 1989. He is director of the Southwest Research Institute's department of space studies in Boulder, Colo.

perience of our team-member institutions at delivering space missions on schedule and at or below cost.

The New Horizons spacecraft we designed is lean, with a planned mass of just 416 kilograms (917 pounds)—heavier than the early Pioneer probes but lighter than the Voyagers. This mass includes the hydrazine maneuvering propellant that will be used to adjust the craft's trajectory in flight. Most of the spacecraft's subsystems, such as its computers and its propulsion-control system, are based on designs used in the APL's Comet Nucleus Tour (CONTOUR) probe, which is scheduled to launch this July on a multiple comet flyby mission. The use of CONTOUR's designs reduces New Horizons's costs and lowers the risk of both technical and schedule problems. Almost all our spacecraft subsystems include spare equipment to increase reliability on the long flight to Pluto and the Kuiper Belt.

The spacecraft will carry four instrument packages. A mapping and compositional spectroscopy package, PERSI, will make observations in the visible, ultraviolet and infrared parts of the spectrum. PERSI's infrared imaging spectrometer will be essential for mapping the composition and physical state (including temperature) of the surface ices on Pluto and Charon. A radio-science instrument dubbed REX will probe Pluto's atmospheric structure and gauge the average surface temperatures of Pluto and Charon (on both the daysides and nightsides of the bodies) by measuring the intensity of the microwave radiation striking the spacecraft's 2.5-meter-wide radio dish. A third instrument suite, PAM, consists of charged-particle detectors designed to sample material escaping from Pluto's atmosphere and to determine its escape rate. The fourth instrument is LORRI, a high-resolution imager that will supplement PERSI's already formidable mapping capabilities. At closest approach, PERSI's global maps of Pluto-Charon and the KBOs will have an average resolution of one kilometer. But LORRI, which will image selected regions, will be able to detect objects 20 times as small!

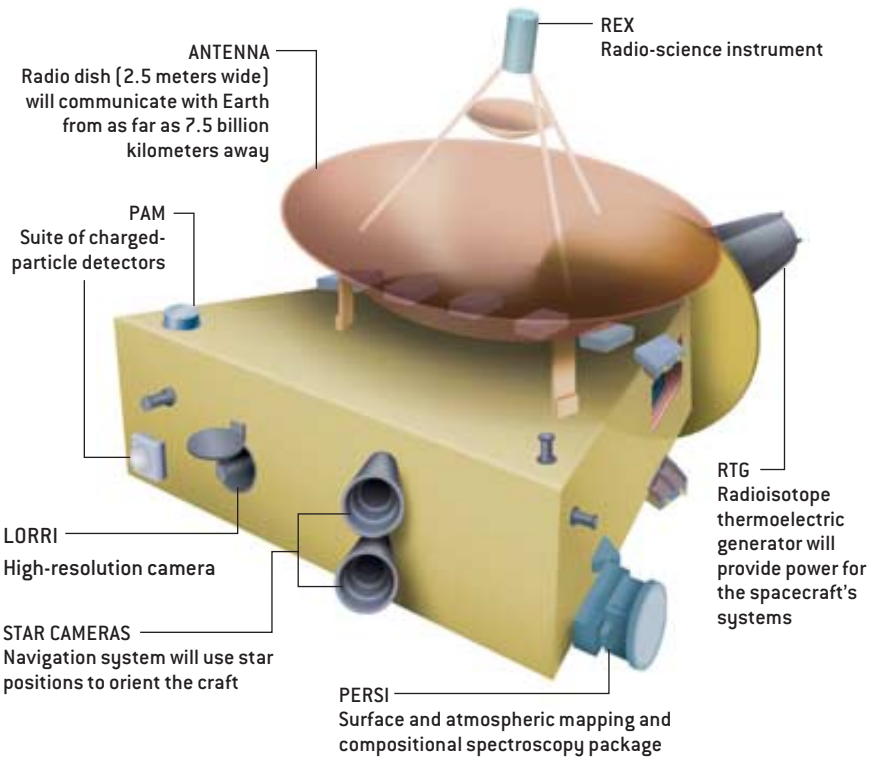
If all goes as planned, the spacecraft will be launched in January 2006, heading initially for a flyby of Jupiter that will use the planet's gravity to slingshot the craft toward Pluto [*see illustration on page 59*]. During its Jupiter flyby, New Horizons will conduct an intensive four-month study of the planet's intriguing system of more than 20 moons, as well as its auroras, atmosphere and magnetosphere. Thanks to the gravitational assist from Jupiter, the spacecraft can reach the Pluto-Charon system as early as 2015. (The exact arrival date depends on the launch vehicle selected by NASA and the precise day we launch in January 2006.)

For much of the long cruise from Jupiter to Pluto, New Horizons will slumber in electronic hibernation. Turning off unneeded systems and reducing the amount of contact with the craft lowers the chance of equipment failures and drastically decreases mission operations costs. During this hibernation the craft will continuously transmit a simple status beacon to Earth; if an unexpected problem develops, our ground-control team will respond. Once each year the craft will be awakened for about 50 days to thoroughly test the systems, make course corrections and calibrate its scientific instruments.

Unlike earlier plans for a quick flyby of Pluto-Charon, New Horizons will begin its study of Pluto-Charon six months before its closest approach to the planet. Once the craft is about 100 million kilometers from Pluto—about 75 days before closest approach—its images of the planet will be better than those of the Hubble Space Telescope, and the results will improve with each passing day. In the weeks before closest approach, our mission

NEW HORIZONS SPACECRAFT

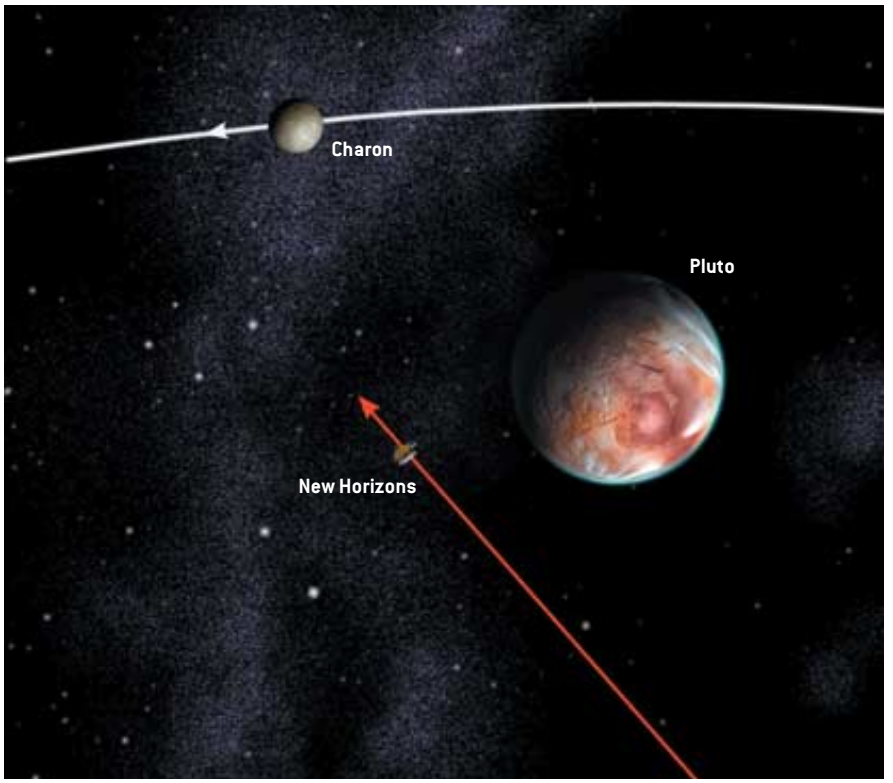
TO EXPLORE Pluto, Charon and the Kuiper Belt objects, the proposed craft will carry four instrument packages, called REX, PAM, PERSI and LORRI.



GENERAL INFORMATION

- The spacecraft has a design mass of 416 kilograms (917 pounds) and is about the size of a small lifeboat.
- On the journey to Pluto, the probe will reach a top speed of about 70,000 kilometers per hour.
- The craft's computers will be able to store 48 gigabits of data and transmit the information to Earth at up to 770 bits per second from Pluto (16,000 bits per second from Jupiter).

JUAN VELASCO



FLYBY OF PLUTO by the New Horizons spacecraft will reach its climax at closest approach, when the craft may come as near as a few thousand kilometers from the planet's surface. The flyby is shown from a perspective within Charon's orbit around Pluto and slightly above the orbital plane.

team will be able to map Pluto-Charon in increasing detail and observe phenomena such as Pluto's weather by comparing the images of the planet over time. And using LORRI's high-resolution imaging capabilities, we will get "zoom-lens" views of Pluto and Charon that will help us decide which geologic features are worthy of special scrutiny. During the day of closest approach, when New Horizons may come as near as a few thousand kilometers from Pluto, PERSI will obtain its best maps of the entire sunlit faces of Pluto and Charon. Meanwhile LORRI will focus on producing higher-resolution maps of dozens of smaller areas on these bodies.

Once the spacecraft passes Pluto, it will turn around and map the planet's nightside, which will be softly illuminated by the reflected moonlight from Charon. And the spacecraft's antenna will receive a powerful radio beam from Earth passing through Pluto's atmosphere. By measuring the refraction of this radio beam, we will be able to plot the temperature and density profile of Pluto's atmosphere from high altitude down to the surface.

After the Pluto-Charon encounter, New Horizons will almost immediately maneuver to begin a series of what we hope will be three or more similar flybys with ancient KBOs over the next five years. The exact number of encounters will depend on how much propellant is left in the spacecraft after the Pluto flyby.

Now—or Never?

THE NEW HORIZONS mission promises to revolutionize our knowledge of both the Pluto-Charon system and the Kuiper Belt. But the potential for discovery will be lost if the mission is not launched in 2006. Because of the changing alignment of the planets, after 2006 the spacecraft will no longer be able to accelerate toward Pluto by swinging past Jupiter. If this window is missed, NASA would have to wait until 2018 for Jupiter to be in the right place again, delaying any encounter until the mid-2020s at the earliest.

By that time Pluto will be hundreds of millions of kilometers farther from the sun and significantly colder than it is today. Because of a combination of Pluto's extreme polar tilt and its motion around the sun, more than four million kilometers of terrain—much of the planet's southern hemisphere—will by then be covered in a dark polar shadow, thereby preventing it from being observed. Also, it is likely that virtually all the planet's atmosphere will have condensed by then, closing off any opportunity to study it until the 23rd century, when the atmosphere should again rise as the planet makes its next close approach to the sun.

New Horizons represents a thrilling return to first-time exploration for NASA's planetary program: for the first time since 1989, when Voyager 2 flew by Neptune, a spacecraft will train its instruments on a new world. The mission offers a scientific bonanza of proportions reminiscent of NASA's historic explorations. And by selecting New Horizons through competitive bidding, NASA reduced costs to dimes on the dollar compared with recent missions to the outer solar system.

If Congress approves the development funding to complete the New Horizons spacecraft, the exploration of Pluto-Charon and the Kuiper Belt will commence with a series of flyby encounters beginning just over a dozen years from now, in the summer of 2015. In supporting this project, the U.S. will at last complete the basic reconnaissance of our solar system that it began in the 1960s with the historic Mariner missions to Venus and Mars. SA

MORE TO EXPLORE

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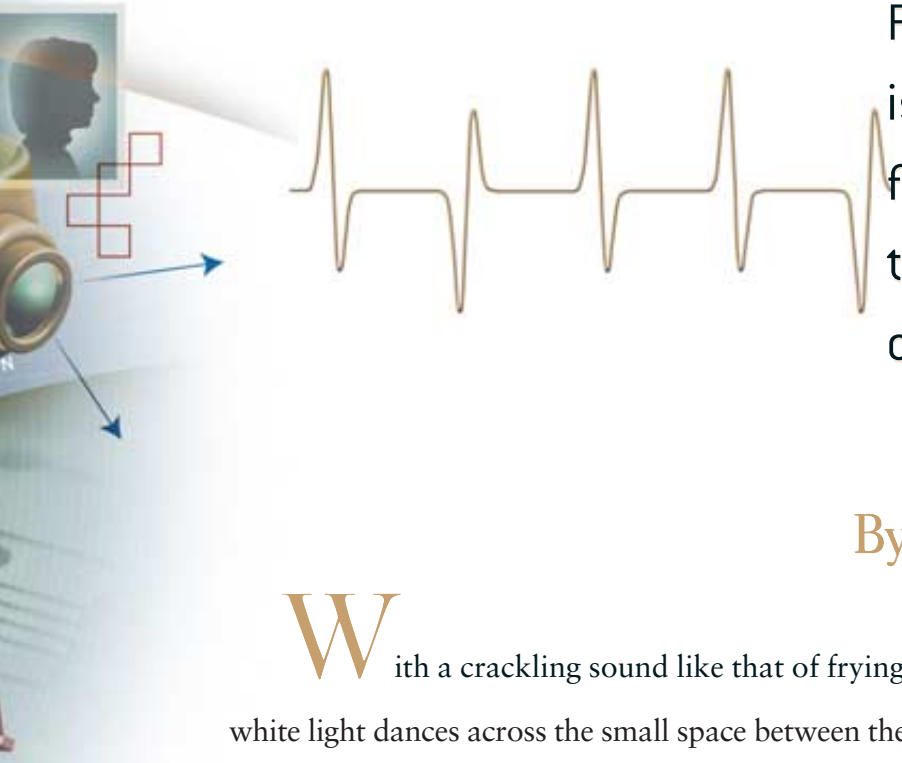
Information about Pluto and Charon is available at **seds.lpl.arizona.edu/nineplanets/nineplanets/pluto.html**

Details of the New Horizons mission are available at **pluto.jhuapl.edu** and at **www.plutomission.com**

DON DIXON

Wireless Data Blaster



Radio's oldest technology is providing a new way for portable electronics to transmit large quantities of data rapidly without wires

By David G. Leeper

With a crackling sound like that of frying eggs, an undulating thread of intense, blue-white light dances across the small space between the tips of two metal rods. Using his spark-gap transmitter, a mild-mannered 31-year-old physics professor demonstrates electromagnetic phenomena to students in a dimly lit classroom at the University of Karlsruhe in Germany. The year is 1887, and Heinrich Hertz is generating radio waves. Seven years later a young Italian named Guglielmo Marconi reads a journal article by Hertz while vacationing in the Alps and abruptly rushes home with a vision of a wireless telegraph in his head. Soon Marconi's own spark-gap transmitters are sending Morse-code pulse streams across his lab without wires. After boosting power and building much larger antennas, the radio pioneer eventually uses the device to transmit coded wireless signals across the Atlantic Ocean in 1901.

TOM WHITE IMAGES

Fast-forward a century, and researchers are once again beaming short electromagnetic pulses across their labs. But the technology has changed. Hertz's and Marconi's bulky coils and capacitors have been replaced by tiny integrated circuits and tunnel diodes. Likewise, the ragged and erratic spark streams emitted by early transmitters have now been refined into precisely timed sequences of specially shaped pulses lasting only a few hundred trillionths of a second each. And whereas Marconi's devices could convey the equivalent of about 10 bits of data per second, today's short-range, low-power descendant of the original spark-gap systems—called ultrawideband (UWB) wireless technology—can send more than 100 million bits of digital information in the same amount of time.

Just Get Me to the Wall

THE HIGH-SPEED data-transfer capabilities of UWB systems have spurred a group of inventors and entrepreneurs [*see table below*] to promote this short-range technology as a nearly ideal way to handle the burgeoning flow of wireless information among networks of portable (battery-powered) electronic devices. These stand-alone networks could include personal digital assistants, digital cameras and camcorders, audio/video players, cell phones, laptop computers and other mobile electronic gear. To exchange the large digital files needed to support increasingly sophisticated broadband applications, these devices require high-bandwidth wireless communications links.

The growing presence of wired connections to the Internet is another driver of short-distance wireless technology. Many in the developed world already spend most of the day within 10 meters of some kind of wired link to the Internet. This proximity opens up the possibility of using short-range wireless technology to communicate between portable electronics and the Internet. As a result, the industry has responded by developing narrowband communications techniques that can "get me to the jack on the wall." These include the IEEE 802.11b and Bluetooth standards, which operate in an unlicensed frequency band from 2.400 to 2.483 gigahertz (GHz), and IEEE 802.11a, which operates indoors on frequencies from 5.150 to 5.350 GHz.

Bluetooth is the best known of what are commonly called wireless personal-area networks (PANs). Wireless PANs were designed to replace the (physical) serial and USB cables used to pass data among closely located electronic equipment. Although specific implementations differ, the low-power Bluetooth standard is expected to offer users a maximum data-transmission speed of about 700 kilobits per second over distances of up to about 10 meters.

The IEEE 802.11a and 802.11b standards were established for wireless local-area networks (LANs), which emphasize faster speeds and longer range but require higher-power consumption. Typically these wireless LANs provide links from laptops to wired LANs via access points. Users of IEEE 802.11b can expect maximum transmission speeds of about 5.5 megabits per second (Mbps) across open-space distances of up to 100 meters. Its companion standard, IEEE 802.11a, will provide users with maximum data speeds of between 24 to 35 Mbps over open spaces of about 50 meters. In practice, all short-range radio systems "downshift" their speeds to compensate for long distances, walls, people and other obstacles.

Ultrawideband wireless technology should make possible an entirely NEW CLASS OF ELECTRONIC DEVICES and functions that would change the way we live.

At present, it appears that semiconductor-based UWB transceivers will be able to provide very high data transmission speeds—100 to 500 Mbps across distances of five to 10 meters. These high bit rates will give rise to applications that are impossible using today's wireless standards. What is more, engineers expect these UWB units to be cheaper, smaller and less power-hungry than today's narrowband radio devices.

UWB is superior to other short-range wireless schemes in another way. Growing demand for greater wireless data capacity and the crowding of regulated radio-frequency spectra favor systems that offer not only high bit rates but high bit rates concentrated in smaller physical areas, a metric that has come to be called spatial capacity. Measured in bits per second per square meter, it is a gauge of "data intensity" in much the same way that lumens per square meter determines the illumination intensity of a light fixture. As increasing numbers of broadband users gather in crowded spaces such as airports, hotels, convention centers and workplaces, the most critical parameter of a wireless system will be its spatial capacity, a capability in which UWB technology excels [*see graph on opposite page*].

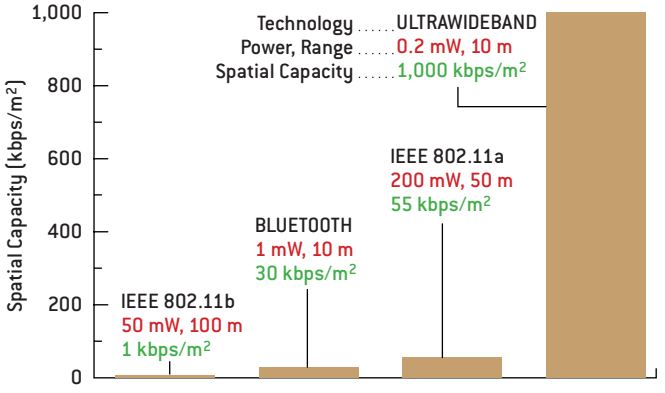
Successful development of UWB wireless technology should make possible an entirely new class of electronic devices and functions that would change the way we live. For example, rather than picking up recorded movies at the video store, we

UWB DEVELOPERS

Aether Wire & Location	www.aetherwire.com
General Atomics	www.ga.com
Multispectral Solutions	www.multispectral.com
Pulse-Link	www.pulse-link.net
Pulsicom Technologies (Israel)	www.pulsicom.com
Time Domain	www.timedomain.com
XtremeSpectrum	www.xtremespectrum.com
Zircon	www.zircon.com

may end up downloading films using a portable mass-storage unit and UWB wireless transmission while filling the car up at the fuel pump. UWB could permit bulky PDA calendars and e-mail directories to be flash-synchronized or messages to be sent or received in public places such as coffee shops, airports, hotels and convention centers. While traveling on planes or trains, people could enjoy streaming video input or interactive games on three-dimensional-vision eyeglasses and high-fidelity audio sets equipped with UWB. Photoenthusiasts could download digital images and video from their cameras to computers or home theaters via UWB wireless, eliminating the rat's nests of cables we often use today.

Comparison of Short-Range Wireless Spatial Capacities



SPATIAL CAPACITY, a gauge of operational efficiency important when comparing short-range wireless systems, favors UWB technology. Measured in kilobits per second per square meter (kbps/m^2), spatial capacity focuses not only on bit rates for data transfer but on bit rates available in the confined spaces defined by short transmission ranges.

UWB technology has other significant, noncommunications applications as well. It relies on razor-thin, precisely timed pulses similar to those used in radar applications. These pulses give UWB wireless the ability to discern buried objects or movement behind walls, capabilities that could be important for rescue and law-enforcement missions.

UWB's precision pulses can also be used to determine the position of emitters indoors. Operating like a local version of the Global Positioning System (GPS) or the LoJack anti-auto-theft technology, a UWB wireless system can triangulate the location of goods tagged with transmitters using multiple receivers placed in the vicinity. This ability might be very useful to department store personnel for doing "virtual inventories"—keeping track of high-value products on the shelves or in the warehouse, for instance. This location-finding feature could also be used to enhance security: UWB receivers installed in "smart" door locks or ATM machines could permit them to operate only when an authorized user—carrying a UWB transmitter—approaches to within a meter or less.

Radio with No Carrier

ULTRAWIDEBAND WIRELESS is unlike familiar forms of radio communications such as AM/FM, short-wave, police/fire, radio, television, and so forth. These narrowband services, which avoid interfering with one another by staying within the confines of their allocated frequency bands, use what is called a carrier wave. Data messages are impressed on the underlying carrier signal by modulating its amplitude, frequency or phase in some way and then are extracted upon reception [*see box on next page for modulation techniques*].

UWB technology is radically different. Rather than employing a carrier signal, UWB emissions are composed of a series of intermittent pulses. By varying the pulses' amplitude, polarity, timing or other characteristic, information is coded into the data stream. Various other terms have been used for the UWB transmission mode—carrierless, baseband, nonsinusoidal and impulse-based among them.

Avoiding Interference

BECAUSE OF THEIR EXTREMELY short duration, these ultrawideband pulses function in a continuous band of frequencies that can span several gigahertz. It turns out that the shorter the pulse, the broader the frequency spectrum that the pulse will occupy [*see box on next page for an explanation of this phenomenon*].

Because the UWB pulses employ the same frequencies as traditional radio services, they can potentially interfere with them. Marconi's spark-gap stations used high power because they needed to bridge great distances. In today's regulatory environment, systems like Marconi's would be intolerable because they would interfere with almost everybody else on the air. Ultrawideband communications systems would share the same problem except that they deliberately operate at power levels so low that they emit less average radio energy than hair dryers, electric drills, laptop computers and other common appliances that radiate electromagnetic energy as a by-product. This low-power output means that UWB's range is sharply restricted—to distances of 100 meters or less and usually as little as 10 meters. For well-chosen modulation schemes, interference from UWB transmitters is generally benign because the energy levels of the pulses are simply too low to cause problems.

As with emissions from home appliances, the average radiated power from UWB transceivers is likewise expected to be too low to pose any biological hazard to users, although further laboratory tests are needed to confirm this fully. A typical 200-microwatt UWB transmitter, for example, radiates only one three-thousandth of the average energy emitted by a conventional 600-milliwatt cell phone.

On February 14 the Federal Communications Commission

THE AUTHOR

DAVID G. LEEPER is chief technologist for wireless technologies in Intel's New Business Investments Group, which is exploring commercial applications for ultrawideband wireless systems. During his 32-year career, he has also held senior management positions at AT&T Bell Labs, Bellcore and Motorola. Leeper enjoys working with small teams to create business opportunities around exciting new technologies. He received a doctorate in electrical engineering from the University of Pennsylvania.

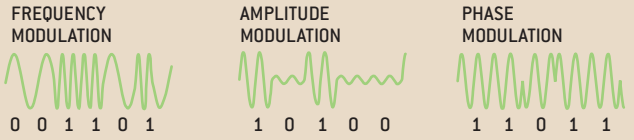
RADIO-SIGNAL TECHNICALITIES

Narrowband and Wideband Modulation Schemes

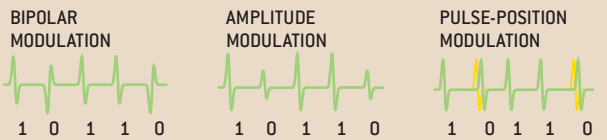
CONVENTIONAL NARROWBAND radio techniques rely on a base "carrier" wave that is altered in a systematic manner (modulated) to embody a coded bit stream. Carrier waves can be modified to incorporate digital data by varying their amplitude, frequency or phase.

Ultrawideband wireless technology uses no underlying carrier wave, instead modulating individual pulses in some way. In a bipolar modulation scheme, a digital 1 is represented by a positive (rising) pulse and a 0 by an inverted (falling) pulse. In another approach, full-amplitude pulses stand for 1's, whereas half-amplitude pulses stand for 0's. Pulse-position modulation sends identical pulses but alters the transmission timing. Delayed pulses indicate 0's.

Narrowband Transmissions



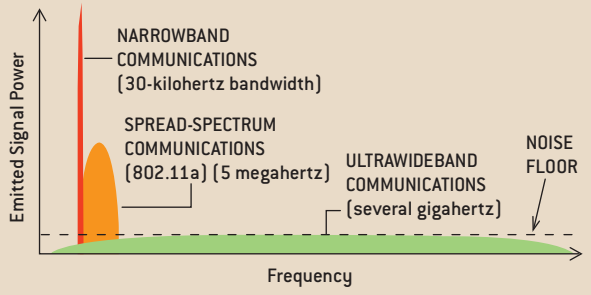
Wideband Transmissions



Why Short Pulses Imply Wide Frequency Bands

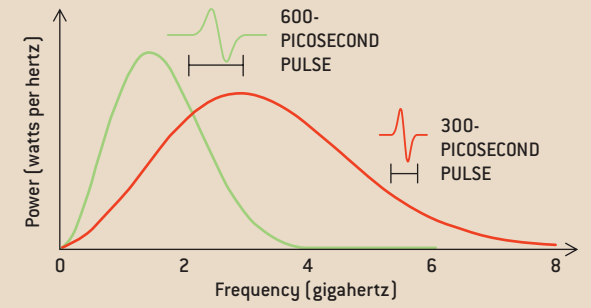
UNLIKE TRADITIONAL COMMUNICATIONS systems, ultrawideband wireless occupies a broad span of frequencies at very low power levels, often below the noise floor of the existing signaling environment (*1*).

1



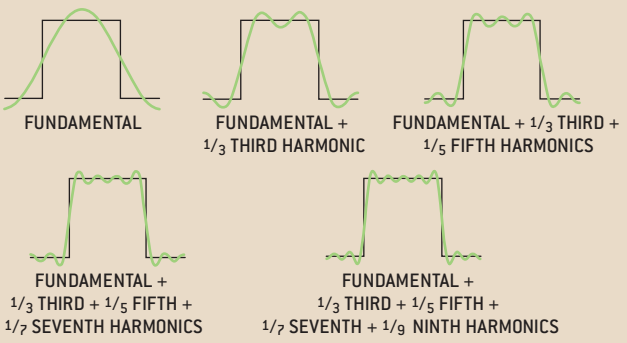
The comparison below (*2*), which depicts typical ultrawideband pulses and their accompanying frequency spectra, shows that the narrower the pulse in time, the higher its center frequency and the broader the spread of its frequency spectrum. (Picoseconds are trillionths of seconds.)

2



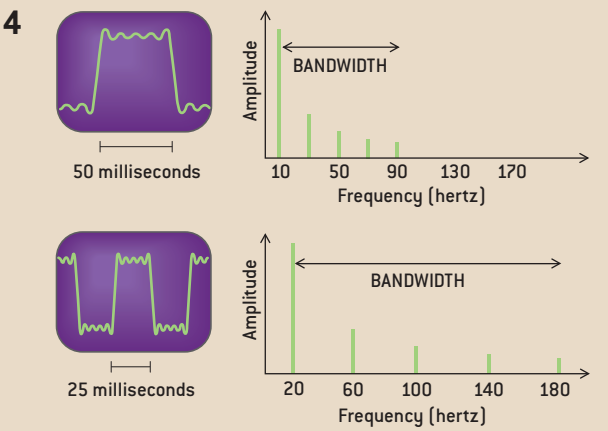
Fourier transform theory explains why the shorter the time interval of a pulse, the broader its bandwidth. The theory says that any waveform can be represented as the appropriately weighted sum of sinusoidal waveforms. For example, a square pulse (in reality, a train of them) can be approximated by a sine wave fundamental (or root) plus sine waves whose frequencies are odd multiples (harmonics) of the fundamental's frequency. Each added harmonic is weaker than the previous one, but the approximation improves with each addition. In principle, an infinite number of additions exactly represents the square wave, but as shown below (*3*), the fundamental plus its first four odd harmonics do a fairly good job.

3 **Fourier Approximation of a Square Wave Pulse**



The figures below (*4*) show the distribution of energy in the fundamental and harmonic waves as functions of their frequencies for Fourier approximations of two pulses. Note that the narrower pulse requires a higher fundamental frequency to represent it. The four added harmonics of that fundamental have a larger spread (or bandwidth) than that of the wider pulse.

4



JOHNNY JOHNSON

gave qualified approval to UWB usage, following nearly two years of commentary by interested parties. Most of the more than 900 comments on the proposed ruling concerned whether UWB might interfere with existing services such as GPS, radar and defense communications, and cell-phone services.

Taking a conservative tack, federal regulators chose to allow UWB communications applications with full "incidental radiation" power limits of between 3.1 and 10.6 GHz. Outside that band, signals must be attenuated by 12 decibels (dB), with 34 dB of attenuation required in areas near the GPS-frequency bands. More liberal restrictions were permitted for law-enforcement and public safety personnel using UWB units to search for earthquake or terrorist attack victims.

Despite the imposed limitations, UWB developers are confident that the wireless technology will be able to accomplish most of the data-transfer tasks its proponents envision for it. The FCC regulators indicated that they will examine easing the constraints once operational experience has been gained and further studies have been conducted.

A typical 200-microwatt UWB transmitter radiates only ONE THREE-THOUSANDTH OF THE AVERAGE ENERGY emitted by a conventional 600-milliwatt cell phone.

Ironically, the more challenging technical problem appears to be finding ways to stop other emitters from interfering with UWB devices. This area is one in which narrowband systems have a decided advantage—all such systems are fitted with a front-end filter that prevents transmitters operating outside their reception bands from causing trouble. Unfortunately, a UWB receiver needs to have a "wide-open" front-end filter that lets through a broad spectrum of frequencies, including signals from potential interferers. The ability of a UWB receiver to overcome this impediment, sometimes called jamming resistance, is a key attribute of good receiver design. One approach to improving jamming resistance is to install so-called notch filters that attenuate those narrow parts of the spectrum where interference is known to be likely. Another protective measure that has been developed would be to use automatic notch filters that seek out and diminish the signals of particularly strong narrowband interferers.

Many Paths to Take

MULTIPATH INTERFERENCE, another kind of radio interference, is also an issue. In some situations, the same narrowband signal can be reflected by surrounding objects onto two or more different paths so the reflected signals arrive at a receiver out of phase, sometimes virtually canceling each other out. Most of us have experienced multipath problems when listening to FM radio in an automobile. When a car is stopped at a traffic light, for example, the signal can suddenly become noisy and distorted. Rolling forward a foot or two, however, often alters the relative timing of the received signals sufficiently to restore clear reception.

Multiple signals caused by reflections might be a liability for UWB wireless units as well, but clever design can permit them to take advantage of the phenomenon. The narrow pulses of UWB make it possible for some receivers to resolve the separate multipath streams and use multiple "arms" to lock onto the various reflected signals. Then, in near real-time, the arms "vote" on whether a received bit is a one or a zero. This bit-checking function actually improves the performance of the receiver.

Go Low and Short

TODAY'S TREND TOWARD sending lower-power signals over shorter ranges has occurred previously in wireless communications—during the early days of radio telephony. Before 1980, a single tower with a high-powered transmitter might cover an entire city, but limited spectrum availability meant that it could not serve many customers. As recently as 1976, radio telephone providers in New York City could handle only 545 mobile telephone customers at a time—an absurdly small number by current standards. Cellular telephony was able to accommodate a greater number of customers by drastically reducing both power and distance, allowing the same spectrum to be reused many times within a geographic area. Now short-range wireless, particularly UWB, is poised to do the same.

There are still some among us who can remember, before 1920, when "spark was king." With help from semiconductors and the Internet, spark-gap radio's latter-day offspring—UWB technology—may soon emerge as a major wireless building block for advanced high-speed data communications. SA

MORE TO EXPLORE

Ultra-Wideband Technology for Short or Medium-Range Wireless Communications. J. Foerster et al. in *Intel Technology Journal,* Q2, 2001. Available at **http://intel.com/technology/itj/q22001/articles/art_4.htm**

A Long-Term View of Short-Range Wireless. David G. Leeper in *IEEE Computer Magazine,* Vol. 34, No. 6, pages 39–44; June 2001.

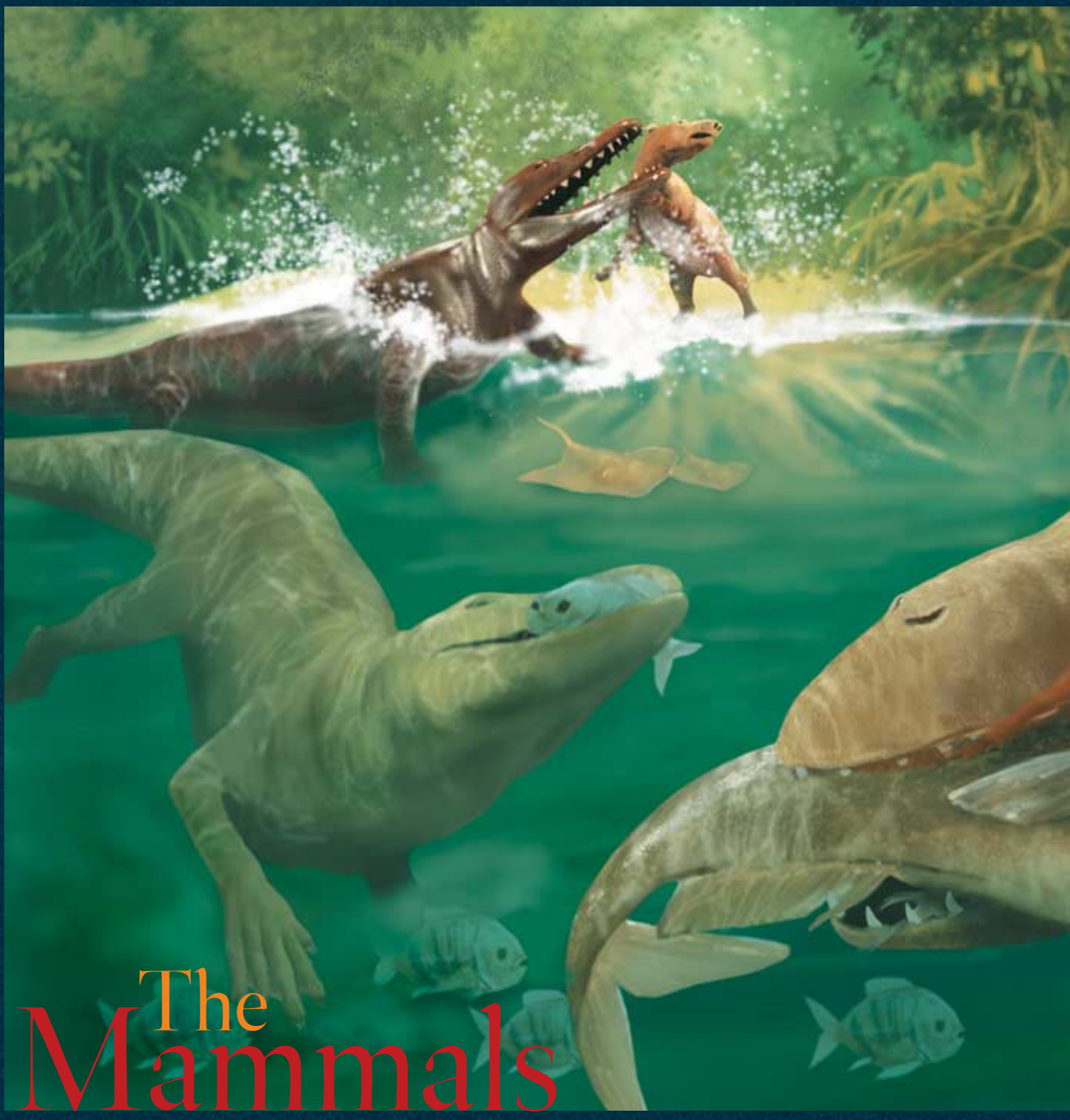
Extensive links to UWB wireless information sources: **www.aetherwire.com**

FCC electronic comment-filing system: **www.fcc.gov/e-file/ecfs.html** (Click on "Search for Filed Comments" and enter "98-153" in the box.)

History of radio Web site: **www.localhistory.scit.wlv.ac.uk/Museum/Engineering/Electronics/history/radiohistory.htm**

Official Bluetooth Web site: **www.bluetooth.com**

Official IEEE 802 Web site: **http://grouper.ieee.org/groups/802**



The Mammals That Conquered the

New fossils and DNA analyses elucidate the remarkable

"They say the sea is cold,
but the sea contains
the hottest blood of all,
and the wildest, the most urgent."

—D. H. Lawrence,
"Whales Weep Not!"

Dawn breaks over the Tethys Sea, 48 million years ago, and the blue-green water sparkles with the day's first light. But for one small mammal, this new day will end almost as soon as it has started.

ANCIENT WHALE *Rodhocetus* (*right* and *left front*) feasts on the bounty of the sea, while *Ambulocetus* (*rear*) attacks a small land mammal some 48 million years ago in what is now Pakistan.

Seas

evolutionary history of whales

By Kate Wong

Tapir-like *Eotitanops* has wandered perilously close to the water's edge, ignoring its mother's warning call. For the brute lurking motionless among the mangroves, the opportunity is simply too good to pass up. It lunges landward, propelled by powerful hind limbs, and sinks its formidable teeth into the calf, dragging it back into the surf. The victim's frantic struggling subsides as it drowns, trapped in the viselike jaws of its captor. Victorious, the beast shambles out of the water to devour its kill on terra firma. At first glance, this fearsome predator resembles a crocodile, with its squat legs, stout tail, long snout and eyes that sit high on its skull. But on closer inspection, it has not armor but fur, not claws but hooves. And the cusps on its teeth clearly identify it not as a reptile but as a mammal. In fact, this improbable creature is *Ambulocetus*, an early whale, and one of a series of intermediates linking the land-dwelling ancestors of cetaceans to the 80 or so species of whales, dolphins and porpoises that rule the oceans today.

Until recently, the emergence of whales was one of the most intractable mysteries facing evolutionary biologists. Lacking fur and hind limbs and unable to go ashore for so much as a sip of freshwater, living cetaceans represent a dramatic departure from the mammalian norm. Indeed, their piscine form led Herman Melville in 1851 to describe Moby Dick and his fellow whales as fishes. But to 19th-century naturalists such as Charles Darwin, these air-breathing, warm-blooded animals that nurse their young with milk distinctly grouped with mammals. And because ancestral mammals lived on land, it stood to reason that whales ultimately descended from a terrestrial ancestor. Exactly how that might have happened, however, eluded scholars. For his part, Darwin noted in *On the Origin of Species* that a bear swimming with its mouth agape to catch insects was a plausible evolutionary starting point for whales. But the proposition attracted so much ridicule that in later editions of the book he said just that such a bear was "almost like a whale."

The fossil record of cetaceans did little to advance the study of whale origins. Of the few remains known, none were sufficiently complete or primitive to throw much light on the matter. And further analyses of the bizarre anatomy of living whales led only to more scientific head scratching. Thus, even a century after Darwin, these aquatic mammals remained an evolutionary enigma. In fact, in his 1945 classification of mammals, famed paleontologist George Gaylord Simpson noted that whales had evolved in the oceans for so long that nothing informative about their ancestry remained. Calling them "on the whole, the most peculiar and aberrant of mammals," he inserted cetaceans arbitrarily among the other orders. Where whales belonged in the mammalian family tree and how they took to the seas defied explanation, it seemed.

Over the past two decades, however, many of the pieces of this once imponderable puzzle have fallen into place. Paleontologists have uncovered a wealth of whale fossils spanning the Eocene epoch, the time between 55 million and 34 million years ago when archaic whales, or archaeocetes, made their transition from land to sea. They have also unearthed some clues from the ensuing Oligocene, when the modern suborders of cetaceans—the mysticetes (baleen whales) and the odontocetes (toothed whales)—arose. That fossil material, along with analyses of DNA from living animals, has enabled scientists to paint a detailed picture of when, where and how whales evolved from their terrestrial forebears. Today their transformation—from landlubbers to Leviathans—stands as one of the most profound evolutionary metamorphoses on record.

Guide to *Terminology*

CETACEA is the order of mammals that comprises living whales, dolphins and porpoises and their extinct ancestors, the archaeocetes. Living members fall into two suborders: the odontocetes, or toothed whales, including sperm whales, pilot whales, belugas, and all dolphins and porpoises; and the mysticetes, or baleen whales, including blue whales and fin whales. The term "whale" is often used to refer to all cetaceans.

MESONYCHIDS are a group of primitive hoofed, wolflike mammals once widely thought to have given rise to whales.

ARTIODACTYLA is the order of even-toed, hoofed mammals that includes camels; ruminants such as cows; hippos; and, most researchers now agree, whales.

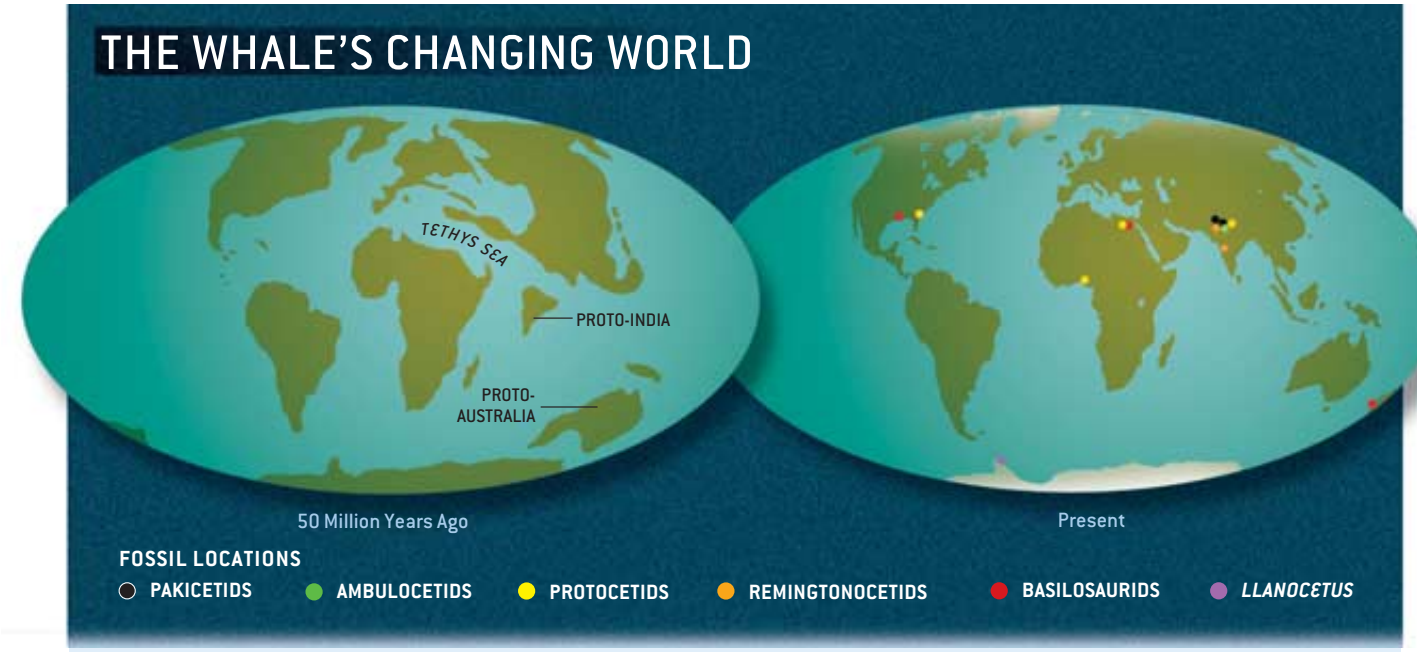
EOCENE is the epoch between 55 million and 34 million years ago, during which early whales made their transition from land to sea.

OLIGOCENE is the epoch between 34 million and 24 million years ago, during which odontocetes and mysticetes evolved from their archaeocete ancestors.

Evolving Ideas

AT AROUND THE SAME TIME that Simpson declared the relationship of whales to other mammals undecipherable on the basis of anatomy, a new comparative approach emerged, one that looked at antibody-antigen reactions in living animals. In response to Simpson's assertion, Alan Boyden of Rutgers University and a colleague applied the technique to the whale question. Their results showed convincingly that among living animals, whales are most closely related to the even-toed hoofed

KAREN CARR *(preceding pages)*



It might seem odd that 300 million years after vertebrates first established a toehold on land, some returned to the sea. But the setting in which early whales evolved offers hints as to what lured them back to the water. For much of the Eocene epoch (roughly between 55 million and 34 million years ago), a sea called Tethys, after a goddess of Greek mythology, stretched from Spain to Indonesia. Although the continents and ocean plates we know now had taken shape, India was still adrift, Australia hadn't yet fully separated from Antarctica, and great swaths of Africa and Eurasia lay submerged under Tethys. Those shallow, warm waters incubated abundant nutrients and teemed with fish. Furthermore, the space vacated by the plesiosaurs, mosasaurs and other large marine reptiles that perished along with the dinosaurs created room for new top predators (although sharks and crocodiles still provided a healthy dose of competition). It is difficult to imagine a more enticing invitation to aquatic life for a mammal.

During the Oligocene epoch that followed, sea levels sank and India docked with the rest of Asia, forming the crumpled interface we know as the Himalayas. More important, University of Michigan paleontologist Philip Gingerich notes, Australia and Antarctica divorced, opening up the Southern Ocean and creating a south circumpolar current that eventually transformed the balmy Eocene earth into the ice-capped planet we inhabit today. The modern current and climate systems brought about radical changes in the quantity and distribution of nutrients in the sea, generating a whole new set of ecological opportunities for the cetaceans.

As posited by paleontologist Ewan Fordyce of the University of Otago in New Zealand, that set the stage for the replacement of the archaeocetes by the odontocetes and mysticetes (toothed and baleen whales, respectively). The earliest known link between archaeocetes and the modern cetacean orders, Fordyce says, is *Llanocetus,* a 34-million-year-old protobaleen whale from Antarctica that may well have trawled for krill in the chilly Antarctic waters, just as living baleen whales do. Odontocetes arose at around the same time, he adds, specializing to become echolocators that could hunt in the deep.

Unfortunately, fossils documenting the origins of mysticetes and odontocetes are vanishingly rare. Low sea levels during the middle Oligocene exposed most potential whale-bearing sediments from the early Oligocene to erosive winds and rains, making that period largely "a fossil wasteland," says paleontologist Mark Uhen of the Cranbrook Institute of Science in Bloomfield Hills, Mich. The later fossil record clearly shows, however, that shortly after, by about 30 million years ago, the baleen and toothed whales had diversified into many of the cetacean families that reign over the oceans today. —*K.W.*

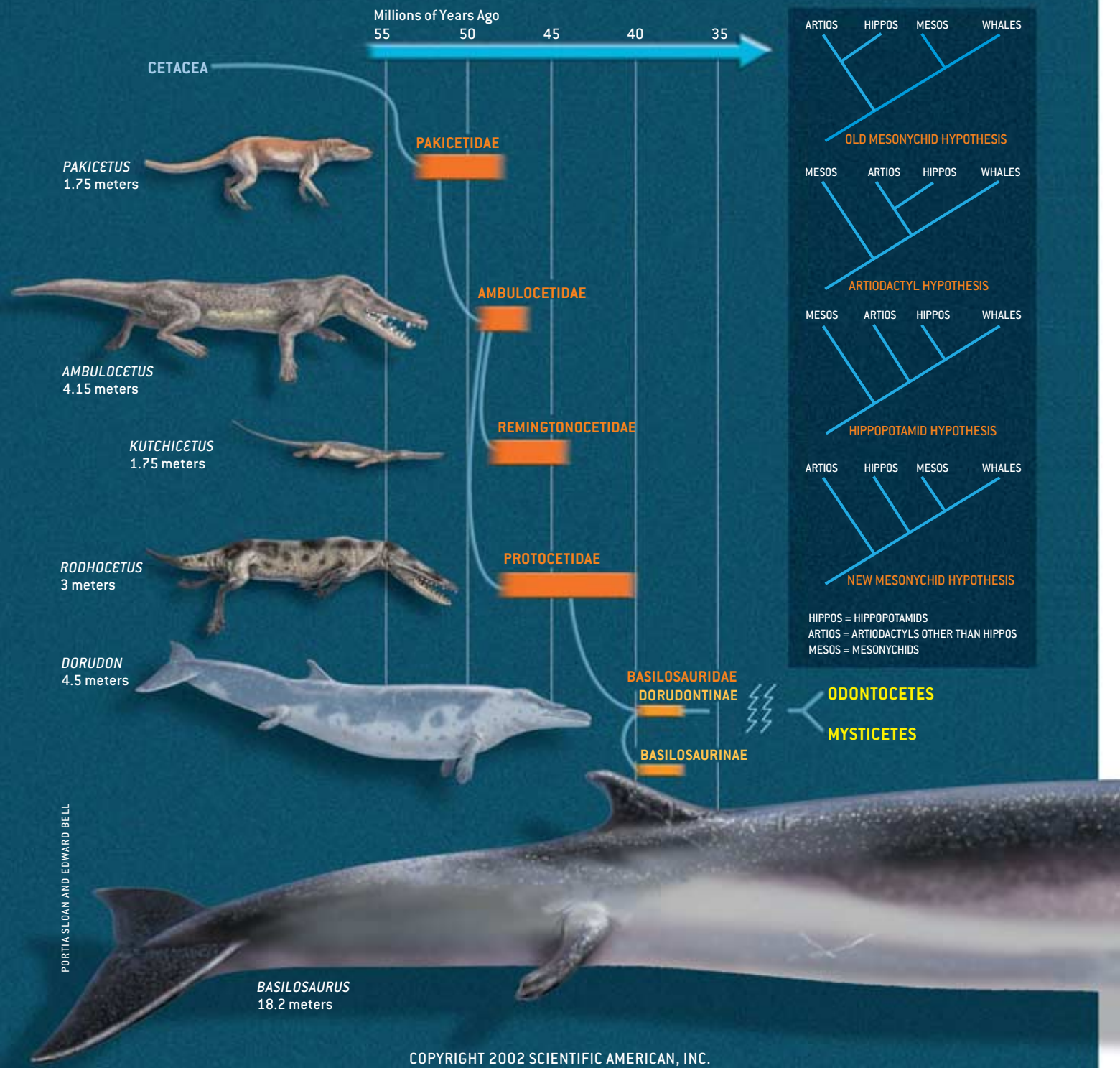
mammals, or artiodactyls, a group whose members include camels, hippopotamuses, pigs and ruminants such as cows. Still, the exact nature of that relationship remained unclear. Were whales themselves artiodactyls? Or did they occupy their own branch of the mammalian family tree, linked to the artiodactyl branch via an ancient common ancestor?

Support for the latter interpretation came in the 1960s, from studies of primitive hoofed mammals known as condylarths that had not yet evolved the specialized characteristics of artiodactyls or the other mammalian orders. Paleontologist Leigh Van Valen, then at the American Museum of Natural History in New York City, discovered striking resemblances between the three-cusped teeth of the few known fossil whales and those of a group of meat-eating condylarths called mesonychids. Likewise, he found shared dental characteristics between artiodactyls and another group of condylarths, the arctocyonids, close relatives of the mesonychids. Van Valen concluded that whales descended from the carnivorous, wolflike mesonychids and thus were linked to artiodactyls through the condylarths.

SARA CHEN AND EDWARD BELL

CETACEAN RELATIONS

FAMILY TREE OF CETACEANS shows the descent of the two modern suborders of whales, the odontocetes and mysticetes, from the extinct archaeocetes. Representative members of each archaeocete family or subfamily are depicted (*left*). Branching diagrams illustrate various hypotheses of the relationship of whales to other mammals (*right*). The old mesonychid hypothesis, which posits that extinct wolflike beasts known as mesonychids are the closest relatives of whales, now seems unlikely in light of new fossil whale discoveries. The anklebones of those ancient whales bear the distinctive characteristics of artiodactyl ankles, suggesting that whales are themselves artiodactyls, as envisioned by the artiodactyl hypothesis. Molecular studies indicate that whales are more closely related to hippopotamuses than to any other artiodactyl group. Whether the fossil record can support the hippopotamid hypothesis, however, remains to be seen. A fourth scenario, denoted here as the new mesonychid hypothesis, proposes that mesonychids could still be the whale's closest kin if they, too, were included in the artiodactyl order, instead of the extinct order Condylarthra, in which they currently reside. If so, they would have to have lost the ankle traits that characterize all known artiodactyls. *—K.W.*



PORTIA SLOAN AND EDWARD BELL

Walking Whales

A DECADE OR SO PASSED before paleontologists finally began unearthing fossils close enough to the evolutionary branching point of whales to address Van Valen's mesonychid hypothesis. Even then the significance of these finds took a while to sink in. It started when University of Michigan paleontologist Philip Gingerich went to Pakistan in 1977 in search of Eocene land mammals, visiting an area previously reported to shelter such remains. The expedition proved disappointing because the spot turned out to contain only marine fossils. Finding traces of ancient ocean life in Pakistan, far from the country's modern coast, is not surprising: during the Eocene, the vast Tethys Sea periodically covered great swaths of what is now the Indian subcontinent [*see box on page 73*]. Intriguingly, though, the team discovered among those ancient fish and snail remnants two pelvis fragments that appeared to have come from relatively large, walking beasts. "We joked about walking whales," Gingerich recalls with a chuckle. "It was unthinkable." Curious as the pelvis pieces were, the only fossil collected during that field season that seemed important at the time was a primitive artiodactyl jaw that had turned up in another part of the country.

Two years later, in the Himalayan foothills of northern Pakistan, Gingerich's team found another weird whale clue: a partial braincase from a wolf-size creature—found in the company of 50-million-year-old land mammal remains—that bore some distinctive cetacean characteristics. All modern whales have features in their ears that do not appear in any other vertebrates. Although the fossil skull lacked the anatomy necessary for hearing directionally in water (a critical skill for living whales), it clearly had the diagnostic cetacean ear traits. The team had discovered the oldest and most primitive whale then known—one that must have spent some, if not most, of its time on land. Gingerich christened the creature *Pakicetus* for its place of origin and, thus hooked, began hunting for ancient whales in earnest.

At around the same time, another group recovered additional remains of *Pakicetus*—a lower jaw fragment and some isolated teeth—that bolstered the link to mesonychids through strong dental similarities. With *Pakicetus* showing up around 50 million years ago and mesonychids known from around the same time in the same part of the world, it looked increasingly likely that cetaceans had indeed descended from the mesonychids or something closely related to them. Still, what the earliest whales looked like from the neck down was a mystery.

Further insights from Pakistan would have to wait, however. By 1983 Gingerich was no longer able to work there because of the Soviet Union's invasion of Afghanistan. He decided to cast his net in Egypt instead, journeying some 95 miles southwest of Cairo to the Western Desert's Zeuglodon Valley, so named for early 20th-century reports of fossils of archaic whales—or zeuglodons, as they were then known—in the area. Like Pakistan, much of Egypt once lay submerged under Tethys. Today the skeletons of creatures that swam in that ancient sea lie entombed in sandstone. After several field seasons, Gingerich and his crew hit pay dirt: tiny hind limbs belonging to a 60-foot-long sea snake of a whale known as *Basilosaurus* and the first evidence of cetacean feet.

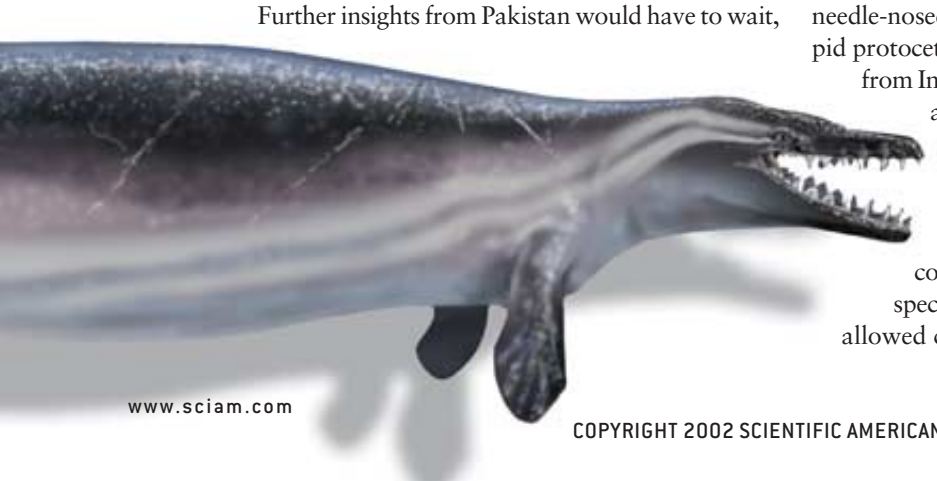
Earlier finds of *Basilosaurus,* a fully aquatic monster that slithered through the seas between some 40 million and 37 million years ago, preserved only a partial femur, which its discoverers interpreted as vestigial. But the well-formed legs and feet revealed by this discovery hinted at functionality. Although at less than half a meter in length the diminutive limbs probably would not have assisted *Basilosaurus* in swimming and certainly would not have enabled it to walk on land, they may well have helped guide the beast's serpentine body during the difficult activity of aquatic mating. Whatever their purpose, if any, the little legs had big implications. "I immediately thought, we're *10 million* years after *Pakicetus,*" Gingerich recounts excitedly. "If these things still have feet and toes, we've got 10 million years of history to look at." Suddenly, the walking whales they had scoffed at in Pakistan seemed entirely plausible.

Just such a remarkable creature came to light in 1992. A team led by J.G.M. (Hans) Thewissen of the Northeastern Ohio Universities College of Medicine recovered from 48-million-year-old marine rocks in northern Pakistan a nearly complete skeleton of a perfect intermediate between modern whales and their terrestrial ancestors. Its large feet and powerful tail bespoke strong swimming skills, while its sturdy leg bones and mobile elbow and wrist joints suggested an ability to locomote on land. He dubbed the animal *Ambulocetus natans,* the walking and swimming whale.

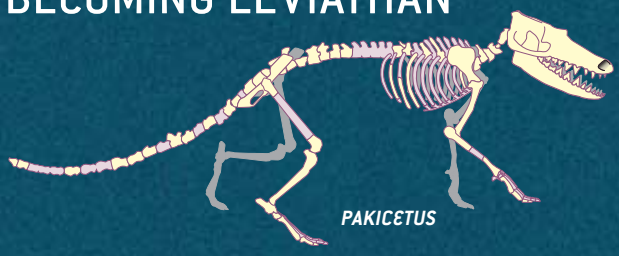
Shape Shifters

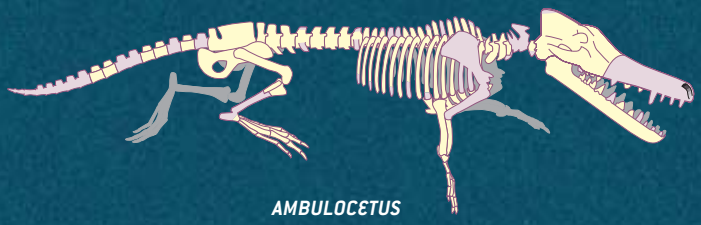
SINCE THEN, Thewissen, Gingerich and others have unearthed a plethora of fossils documenting subsequent stages of the whale's transition from land to sea. The picture emerging from those specimens is one in which *Ambulocetus* and its kin—themselves descended from the more terrestrial pakicetids—spawned needle-nosed beasts known as remingtonocetids and the intrepid protocetids—the first whales seaworthy enough to fan out from Indo-Pakistan across the globe. From the protocetids arose the dolphinlike dorudontines, the probable progenitors of the snakelike basilosaurines and modern whales [*see box on opposite page*].

In addition to furnishing supporting branches for the whale family tree, these discoveries have enabled researchers to chart many of the spectacular anatomical and physiological changes that allowed cetaceans to establish permanent residency in the

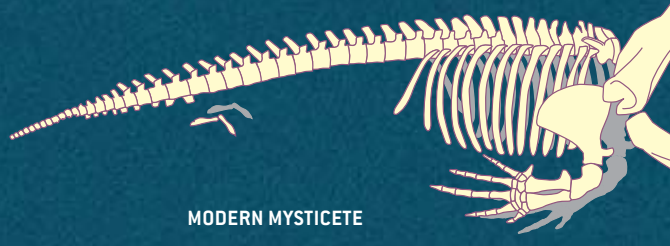


BECOMING LEVIATHAN





REPRESENTATIVE ARCHAEOCETES in the lineage leading to modern odontocetes and mysticetes trace some of the anatomical changes that enabled these animals to take to the seas (reconstructed bone appears in lavender). In just 15 million years, whales shed their terrestrial trappings and became fully adapted to aquatic life. Notably, the hind limbs diminished, the forelimbs transformed into flippers, and the vertebral column evolved to permit tail-powered swimming. Meanwhile the skull changed to enable underwater hearing, the nasal opening moved backward to the top of the skull, and the teeth simplified into pegs for grasping instead of grinding. Later in whale evolution, the mysticetes' teeth were replaced with baleen.

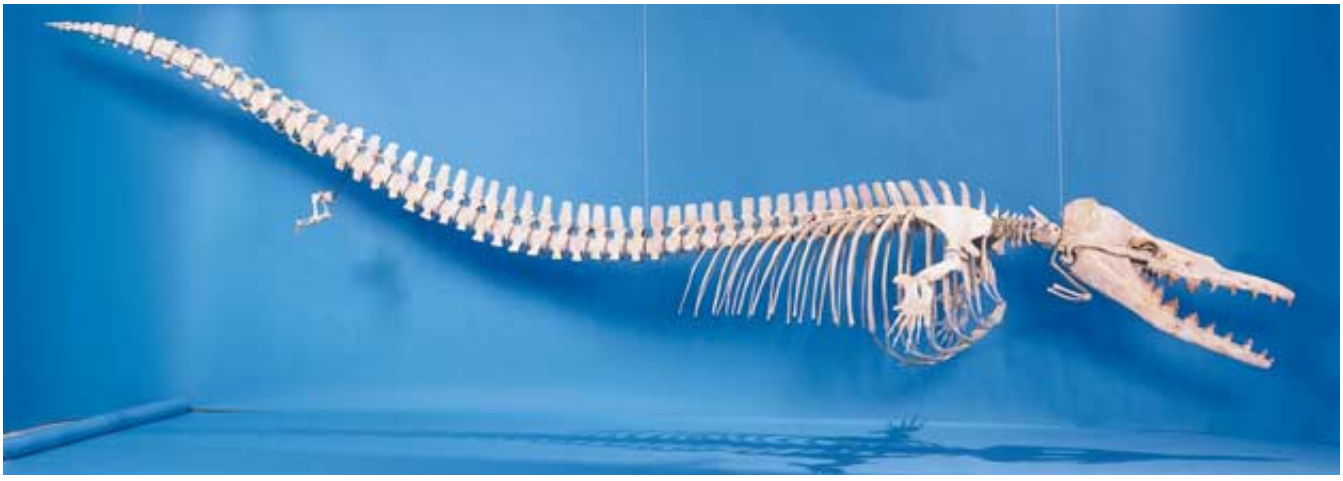


ocean realm. Some of the earliest of these adaptations to emerge, as *Pakicetus* shows, are those related to hearing. Sound travels differently in water than it does in air. Whereas the ears of humans and other land-dwelling animals have delicate, flat eardrums, or tympanic membranes, for receiving airborne sound, modern whales have thick, elongate tympanic ligaments that cannot receive sound. Instead a bone called the bulla, which in whales has become quite dense and is therefore capable of transmitting sound coming from a denser medium to deeper parts of the ear, takes on that function. The *Pakicetus* bulla shows some modification in that direction, but the animal retained a land mammal–like eardrum that could not work in water.

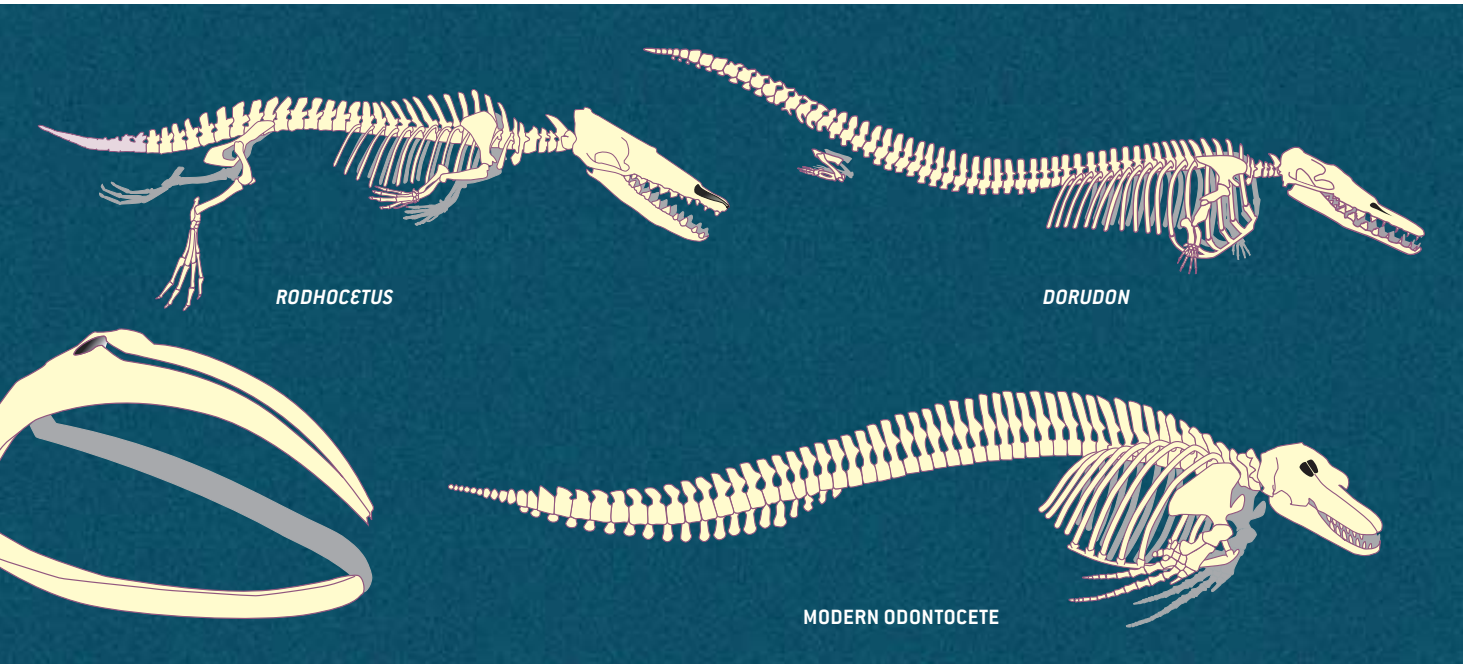
What, then, might *Pakicetus* have used its thickened bullae for? Thewissen suspects that much as turtles hear by picking up vibrations from the ground through their shields, *Pakicetus* may have employed its bullae to pick up ground-borne sounds. Taking new postcranial evidence into consideration along with the ear morphology, he envisions *Pakicetus* as an ambush predator that may have lurked around shallow rivers, head to the ground, preying on animals that came to drink. *Ambulocetus* is even more likely to have used such inertial hearing, Thewissen says, because it had the beginnings of a channel linking jaw and ear. By resting its jaw on the ground—a strategy seen in modern crocodiles—*Ambulocetus* could have listened for approaching prey. The same features that allowed early whales to receive sounds from soil, he surmises, preadapted them to hearing in the water.

Zhe-Xi Luo of the Carnegie Museum of Natural History in Pittsburgh has shown that by the time of the basilosaurines and dorudontines, the first fully aquatic whales, the ropelike tympanic ligament had probably already evolved. Additionally, air

DORUDON, a 4.5-meter-long, dolphinlike archaeocete that patrolled the seas between roughly 40 million and 37 million years ago, may be the ancestor of modern whales.



PORTIA SLOAN (*illustrations*); UNIVERSITY OF MICHIGAN EXHIBIT MUSEUM OF NATURAL HISTORY (*photograph*)



sinuses, presumably filled with spongelike tissues, had formed around the middle ear, offering better sound resolution and directional cues for underwater hearing. Meanwhile, with the external ear canal closed off (a prerequisite for deep-sea diving), he adds, the lower jaw was taking on an increasingly important auditory role, developing a fat-filled canal capable of conducting sound back to the middle ear.

Later in the evolution of whale hearing, the toothed and baleen whales parted ways. Whereas the toothed whales evolved the features necessary to produce and receive high-frequency sounds, enabling echolocation for hunting, the baleen whales developed the ability to produce and receive very low frequency sounds, allowing them to communicate with one another over vast distances. Fossil whale ear bones, Luo says, show that by around 28 million years ago early odontocetes already had some of the bony structures necessary for hearing high-pitched sound and were thus capable of at least modest echolocation. The origin of the mysticete's low-frequency hearing is far murkier, even though the fossil evidence of that group now dates back to as early as 34 million years ago.

Other notable skull changes include movement of the eye sockets from a crocodilelike placement atop the head in *Pakicetus* and *Ambulocetus* to a lateral position in the more aquatic protocetids and later whales. And the nasal opening migrated back from the tip of the snout in *Pakicetus* to the top of the head in modern cetaceans, forming the blowhole. Whale dentition morphed, too, turning the complexly cusped, grinding molars of primitive mammalian ancestors into the simple, pronglike teeth of modern odontocetes, which grasp and swallow their food without chewing. Mysticetes lost their teeth altogether and developed comblike plates of baleen that hang from their upper jaws and strain plankton from the seawater.

The most obvious adaptations making up the whale's protean shift are those that produced its streamlined shape and unmatched swimming abilities. Not surprisingly, some bizarre amphibious forms resulted along the way. *Ambulocetus,* for one, retained the flexible shoulder, elbow, wrist and finger joints of its terrestrial ancestors and had a pelvis capable of supporting its weight on land. Yet the creature's disproportionately large hind limbs and paddlelike feet would have made walking somewhat awkward. These same features were perfect for paddling around in the fish-filled shallows of Tethys, however.

Moving farther out to sea required additional modifications, many of which appear in the protocetid whales. Studies of one member of this group, *Rodhocetus,* indicate that the lower arm bones were compressed and already on their way to becoming hydrodynamically efficient, says University of Michigan paleontologist Bill Sanders. The animal's long, delicate feet were probably webbed, like the fins used by scuba divers. *Rodhocetus* also exhibits aquatic adaptations in its pelvis, where fusion between the vertebrae that form the sacrum is reduced, loosening up the lower spine to power tail movement. These features, says Gingerich, whose team discovered the creature, suggest that *Rodhocetus* performed a leisurely dog paddle at the sea surface and a swift combination of otterlike hind-limb paddling and tail propulsion underwater. When it went ashore to breed or perhaps to bask in the sun, he proposes, *Rodhocetus* probably hitched itself around somewhat like a modern eared seal or sea lion.

By the time of the basilosaurines and dorudontines, whales were fully aquatic. As in modern cetaceans, the shoulder remained mobile while the elbow and wrist stiffened, forming flippers for steering and balance. Farther back on the skeleton, only tiny legs remained, and the pelvis had dwindled accordingly. Analyses of the vertebrae of *Dorudon,* conducted by Mark D. Uhen of the Cranbrook Institute of Science in Bloomfield Hills, Mich., have revealed one tail vertebra with a rounded profile.

Modern whales have a similarly shaped bone, the ball vertebra, at the base of their fluke, the flat, horizontal structure capping the tail. Uhen thus suspects that basilosaurines and dorudontines had tail flukes and swam much as modern whales do, using so-called caudal oscillation. In this energetically efficient mode of locomotion, motion generated at a single point in the vertebral column powers the tail's vertical movement through the water, and the fluke generates lift.

Exactly when whales lost their legs altogether remains unknown. In fact, a recent discovery made by Lawrence G. Barnes of the Natural History Museum of Los Angeles County hints at surprisingly well developed hind limbs in a 27-million-year-old baleen whale from Washington State, suggesting that whale legs persisted far longer than originally thought. Today, however, some 50 million years after their quadrupedal ancestors first waded into the warm waters of Tethys, whales are singularly sleek. Their hind limbs have shrunk to externally invisible vestiges, and the pelvis has diminished to the point of serving merely as an anchor for a few tiny muscles unrelated to locomotion.

WATER, WATER EVERYWHERE

MOST MAMMALS—big ones in particular—cannot live without freshwater. For marine mammals, however, freshwater is difficult to come by. Seals and sea lions obtain most of their water from the fish they eat (some will eat snow to get freshwater), and manatees routinely seek out freshwater from rivers. For their part, cetaceans obtain water both from their food and from sips of the briny deep.

When did whales, which evolved from a fairly large (and therefore freshwater-dependent) terrestrial mammal, develop a system capable of handling the excess salt load associated with ingesting seawater? Evidence from so-called stable oxygen isotopes has provided some clues. In nature, oxygen mainly occurs in two forms, or isotopes: ^{16}O and ^{18}O. The ratios of these isotopes in freshwater and seawater differ, with seawater containing more ^{18}O. Because mammals incorporate oxygen from drinking water into their developing teeth and bones, the remains of those that imbibe seawater can be distinguished from those that take in freshwater.

J.G.M. (Hans) Thewissen of the Northeastern Ohio Universities College of Medicine and his colleagues thus analyzed the oxygen isotope ratios in ancient whale teeth to gain insight into when these animals might have moved from a freshwater-based osmoregulatory system to a seawater-based one. Oxygen isotope values for pakicetids, the most primitive whales, indicate that they drank freshwater, as would be predicted from other indications that these animals spent much of their time on land. Isotope measurements from amphibious *Ambulocetus,* on the other hand, vary widely, and some specimens show no evidence of seawater intake. In explanation, the researchers note that although *Ambulocetus* is known to have spent time in the sea (based on the marine nature of the rocks in which its fossils occur), it may still have had to go ashore to drink. Alternatively, it may have spent the early part of its life (when its teeth mineralized) in freshwater and only later entered the sea.

The protocetids, however, which show more skeletal adaptations to aquatic life, exhibit exclusively marine isotope values, indicating that they drank only seawater. Thus, just a few million years after the first whales evolved, their descendants had adapted to increased salt loads. This physiological innovation no doubt played an important role in facilitating the protocetids' dispersal across the globe. —*K.W.*

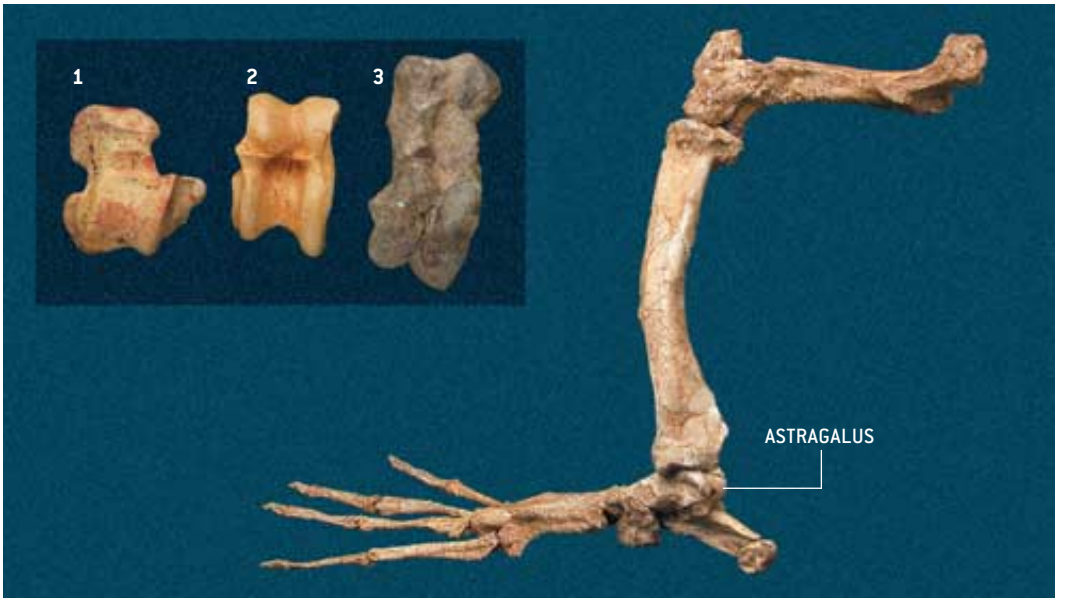
Making Waves

THE FOSSILS UNCOVERED during the 1980s and 1990s advanced researchers' understanding of whale evolution by leaps and bounds, but all morphological signs still pointed to a mesonychid origin. An alternative view of cetacean roots was taking wing in genetics laboratories in the U.S., Belgium and Japan, however. Molecular biologists, having developed sophisticated techniques for analyzing the DNA of living creatures, took Boyden's 1960s immunology-based conclusions a step further. Not only were whales more closely related to artiodactyls than to any other living mammals, they asserted, but in fact whales were themselves artiodactyls, one of many twigs on that branch of the mammalian family tree. Moreover, a number of these studies pointed to an especially close relationship between whales and hippopotamuses. Particularly strong evidence for this idea came in 1999 from analyses of snippets of noncoding DNA called SINES (short interspersed elements), conducted by Norihiro Okada and his colleagues at the Tokyo Institute of Technology.

The whale-hippo connection did not sit well with paleontologists. "I thought they were nuts," Gingerich recollects. "Everything we'd found was consistent with a mesonychid origin. I was happy with that and happy with a connection through mesonychids to artiodactyls." Whereas mesonychids appeared at the right time, in the right place and in the right form to be considered whale progenitors, the fossil record did not seem to contain a temporally, geographically and morphologically plausible artiodactyl ancestor for whales, never mind one linking whales and hippos specifically. Thewissen, too, had largely dismissed the DNA findings. But "I stopped rejecting it when Okada's SINE work came out," he says.

It seemed the only way to resolve the controversy was to find, of all things, an ancient whale anklebone. Morphologists have traditionally defined artiodactyls on the basis of certain features in one of their anklebones, the astragalus, that enhance mobility. Specifically, the unique artiodactyl astragalus has two grooved, pulleylike joint surfaces. One connects to the tibia, or shinbone; the other articulates with more distal anklebones. If whales descended from artiodactyls, researchers reasoned, those that had not yet fully adapted to life in the seas should exhibit this double-pulleyed astragalus.

That piece of the puzzle fell into place last fall, when Gingerich and Thewissen both announced discoveries of new primitive whale fossils. In the eastern part of Baluchistan Province,



HIND LIMB of an ancient whale, *Rodhocetus,* preserves a long-sought anklebone known as the astragalus (*at right*). Shown in the inset beside a mesonychid astragalus (*1*) and one from a modern artiodactyl (*2*), the *Rodhocetus* astragalus (*3*) exhibits the distinctive double-pulley shape that characterizes all artiodactyl astragali, suggesting that whales descended not from mesonychids as previously thought but from an ancient artiodactyl.

Gingerich's team had found partially articulated skeletons of *Rodhocetus balochistanensis* and a new protocetid genus, *Artiocetus*. Thewissen and his colleagues recovered from a bone bed in the Kala Chitta Hills of Punjab, Pakistan, much of the long-sought postcranial skeleton of *Pakicetus,* as well as that of a smaller member of the pakicetid family, *Ichthyolestes*. Each came with an astragalus bearing the distinctive artiodactyl characteristics.

The anklebones convinced both longtime proponents of the mesonychid hypothesis that whales instead evolved from artiodactyls. Gingerich has even embraced the hippo idea. Although hippos themselves arose long after whales, their purported ancestors—dog- to horse-size, swamp-dwelling beasts called anthracotheres—date back to at least the middle Eocene and may thus have a forebear in common with the cetaceans. In fact, Gingerich notes that *Rodhocetus* and anthracotheres share features in their hands and wrists not seen in any other later artiodactyls. Thewissen agrees that the hippo hypothesis holds much more appeal than it once did. But he cautions that the morphological data do not yet point to a particular artiodactyl, such as the hippo, being the whale's closest relative, or sister group. "We don't have the resolution yet to get them there," he remarks, "but I think that will come."

What of the evidence that seemed to tie early whales to mesonychids? In light of the new ankle data, most workers now suspect that those similarities probably reflect convergent evolution rather than shared ancestry and that mesonychids represent an evolutionary dead end. But not everyone is convinced. Maureen O'Leary of the State University of New York at Stony Brook argues that until all the available evidence—both morphological and molecular—is incorporated into a single phylogenetic analysis, the possibility remains that mesonychids belong at the base of the whale pedigree. It is conceivable, she says, that mesonychids are actually ancient artiodactyls but ones that reversed the ankle trend. If so, mesonychids could still be the whales' closest relative, and hippos could be their closest living relative [*see box on page 74*]. Critics of that idea, however, point out that although folding the mesonychids into the artiodactyl order offers an escape hatch of sorts to supporters of the mesonychid hypothesis, it would upset the long-standing notion that the ankle makes the artiodactyl.

Investigators agree that figuring out the exact relationship between whales and artiodactyls will most likely require finding additional fossils—particularly those that can illuminate the beginnings of artiodactyls in general and hippos in particular. Yet even with those details still unresolved, "we're really getting a handle on whales from their origin to the end of archaeocetes," Uhen reflects. The next step, he says, will be to figure out how the mysticetes and odontocetes arose from the archaeocetes and when their modern features emerged. Researchers may never unravel all the mysteries of whale origins. But if the extraordinary advances made over the past two decades are any indication, with continued probing, answers to many of these lingering questions will surface from the sands of time. SA

Kate Wong is a writer and editor for ScientificAmerican.com

MORE TO EXPLORE

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DAN ERICKSON

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EXTREME LIGHT

Focusing light with the power of 1,000 HOOVER DAMS onto a point the size of A CELL NUCLEUS accelerates electrons to the speed of light in a femtosecond

By Gérard A. Mourou and Donald Umstadter

The dream of intensifying light is as old as civilization. Legend has it that Archimedes focused the sun's rays with a giant mirror to set the Roman fleet afire at Syracuse in 212 B.C. Although that story is a myth, it is true that around 200 B.C. another Greek, Diocles, had invented the first ideal focusing optic, a parabolic mirror. Two millennia later mirrors and quantum mechanics were put together to make the most versatile of high-intensity light sources: the laser.

The epitome of high-power lasers is Nova, which operated at Lawrence Livermore National Laboratory from 1985 to 1999. Named for the brilliance of an exploding star, Nova was one of the largest lasers ever built. Ten parallel chains of laser amplifiers occupied a 300-foot enclosure; mirrors made from 400-pound blocks of glass directed the beams to targets for nuclear fusion and other experiments. Nova was fired no more than a few times each day to avoid overheating. Clearly, it marshaled a lot of energy to achieve its ultrahigh power.

Yet power is the *rate* at which energy is delivered, so another approach to ultrahigh power is to release a modest amount of energy in an extremely short time. Nova's usual pulses were relatively long by the standards of today's ultrafast lasers—three nanoseconds—and each one required kilojoules of energy. By using pulses of one ten-thousandth their durations, a new type of laser that fits on a tabletop can deliver power similar to Nova's [see "Ultrashort-Pulse Lasers: Big Payoffs in a Flash," by John-Mark Hopkins and

TABLETOP LASER fires terawatt pulses 10 times a second, striking a thin cloth in the foreground. The photograph is a triple exposure to accommodate the range of intensities.

Wilson Sibbett; SCIENTIFIC AMERICAN, September 2000]. For example, an ultrahigh-power laser that delivers a mere joule in a pulse lasting 100 femtoseconds (10^{-13} second) achieves 10 trillion watts (10^{13} W, or 10 terawatts), more than the output of all the world's power plants combined.

These compact lasers can fire a hundred million shots per day and can concentrate their power onto a spot the size of a micron, producing the highest light intensities on earth. Associated with these gargantuan power densities are the largest electric fields ever produced, in the range of a trillion volts per centimeter. Such intense laser light interacting with matter re-creates the extreme physical conditions that can be found only in the cores of stars or in the vicinity of a black hole: the highest temperatures, 10^{10} kelvins; the largest magnetic fields, 10^9 gauss; and the largest acceleration of particles, 10^{25} times the earth's gravity.

Costing $1 million instead of several hundred million dollars, these lasers are helping to bring "big science" back to standard university laboratories and to countries with limited research budgets. Dozens of such systems have been built throughout the world in the past few years, for use in research in several subfields of physics, including nuclear physics, astrophysics, high-energy particle physics and general relativity. This new breed of laser has already spawned applications, such as x-ray lasers, ultracompact particle accelerators and precision medical radiography. It also shows great promise for radiation therapy and improvements in nuclear fusion power generation.

The Trick

IN THE FIVE YEARS after the invention of the laser in 1960, tabletop lasers advanced in a series of technological leaps to reach a power of one gigawatt (10^9 W). For the next 20 years, progress was stymied and the maximum power of tabletop laser systems did not grow. The sole way to increase power was to build ever larger lasers. Trying to operate beyond the limiting intensity would create unwanted nonlinear effects in components of the laser, impairing the beam quality and even damaging the components. Only in 1985 was this optical damage problem circumvented, with the introduction of a technique known as chirped pulse amplification (CPA) by the research group led by one of us (Mourou). Tabletop laser powers then leaped ahead by factors of 10^3 to 10^5.

Overview/*Extreme Light*

- A method of laser amplification invented in the mid-1980s has enabled a new generation of tabletop lasers that produce very brief pulses of extremely intense light.
- Light of such high intensity interacts with matter in new ways, directly propelling electrons to nearly the speed of light in femtoseconds. The lasers can accelerate particles at 10,000 times the rate of standard accelerators.
- Potential applications include high-resolution medical imaging, inexpensive precision radiation therapy, nuclear fusion, and research in numerous subfields of physics.

"Chirping" a signal or a wave means stretching it in time. In chirped pulse amplification, the first step is to produce a short pulse with an oscillator and stretch it, usually 10^3 to 10^5 times as long [*see illustration on opposite page*]. This operation decreases the intensity of the pulse by the same amount. Standard laser amplification techniques can now be applied to this pulse. Finally, a sturdy device, such as a pair of diffraction gratings in a vacuum, recompresses the pulse to its original duration—increasing its power 10^3 to 10^5 times beyond the amplifier's limit. A typical example would begin with a seed pulse lasting 100 femtoseconds and having 0.2 nanojoule of energy. We stretch it by a factor of 10^4 to a nanosecond (reducing its power from about two kilowatts to 0.2 watt) and amplify it by 10 orders of magnitude to two joules and two gigawatts. Recompressing the pulse to 100 femtoseconds increases the power to 20 terawatts. Without this technique, sending the original two-kilowatt pulse through a tabletop amplifier would have destroyed the amplifier—unless we increased the amplifier's cross-sectional area 10^4 times and dispersed the beam across it. The CPA technique makes it possible to use conventional laser amplifiers and to stay below the onset of nonlinear effects.

Perfecting CPA was not as straightforward as it sounds. Typical devices used to stretch or compress pulses generally do not do so in an exactly linear fashion, and the result will be spoiled if the characteristics of the chirper and the compressor are not closely matched.

A further increase in light intensities has occurred in the past few years with the development of corrective optics that allow laser beams to be focused onto much smaller spot sizes. That advance and further improvements in pulse compression techniques have resulted in pulses that have the maximum possible intensity for a given energy of light.

These increases in power and intensity in the 1990s opened up a new regime of interactions between light and matter, known as relativistic optics, in which the light accelerates electrons close to the speed of light. Prior to CPA, this regime could be reached only by very large and expensive laser systems.

Relativistic Optics

OPTICS IS THE STUDY of how electrons respond to light. That definition may not sound like what many people think of as optics—light reflecting off mirrors or being refracted by the water of a swimming pool. Yet all the optical properties of a material are a consequence of how light interacts with electrons in the material.

Light is a wave composed of coupled electric and magnetic fields oscillating in synchrony at very high frequencies. The electric and magnetic fields oscillate perpendicular to each other and perpendicular to the direction the light is traveling [*see illustration on page 84*]. When an electron encounters a light wave of ordinary power, the electric field of the wave exerts a force on the electron and makes it oscillate. The electron oscillates parallel to the electric field and at the same frequency, but it does not necessarily oscillate in phase with the light wave. Depending on how the electron is bound to the atoms of the material,

Tabletop ultrahigh-intensity lasers are bringing "big science" back to standard university laboratories.

its oscillations may lag behind or lead those of the light wave. The amplitudes and phases of these electron oscillations in turn determine how the light wave propagates through the material and thereby confer on the material its optical properties.

In classical optics the amplitudes are small enough that the electrons' oscillation velocities are always very small compared with the speed of light. With the advent of laser intensities above 10^{18} watts per square centimeter, however, the electrons' oscillation velocities approach the speed of light, and relativistic effects fundamentally change the electrons' response to the light.

First, a high velocity increases the mass of an electron, which affects the amplitude and phase of its oscillations. More important, the magnetic field of the light wave starts to play a role. A magnetic field exerts a force on an electric charge only when the charge is moving. In the regime of classical optics the magnetic force is negligible. But for electron oscillation velocities near the speed of light, it curls the paths of the electrons and gives them tremendous momentum in the direction of the light beam. This effect plays a central role in relativistic optics.

The interaction of light with atomic nuclei can usually be ignored because protons are almost 2,000 times as massive as electrons and therefore oscillate much less. But at high enough intensities, the light starts moving protons around at relativistic velocities as well. That regime may be called nuclear optics because of the great variety of nuclear processes, such as fusion, that can occur.

"0 to 60" (MeV) in a Millimeter

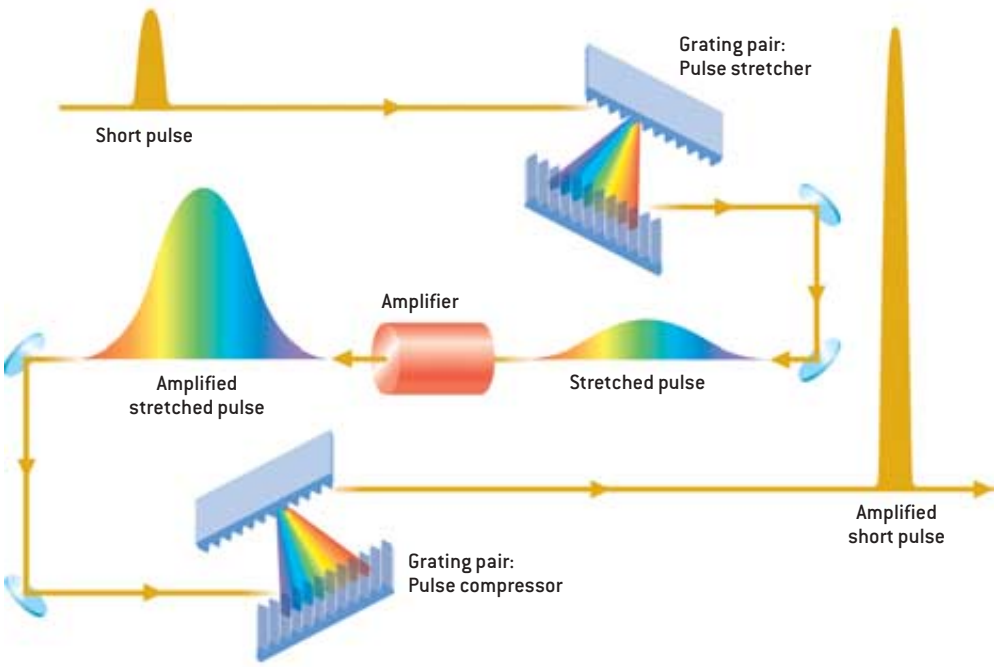
THE MOST OBVIOUS APPLICATION of the relativistic force of an ultraintense laser beam is to accelerate particles. Charged-particle accelerators have numerous uses, ranging from television tubes to cancer therapy to the study of the fundamental forces of the universe. What they all have in common is that the particles, such as electrons or protons, are accelerated by electric or magnetic fields. Although light waves in the regime of classical optics can have electric fields as strong as those near bolts of lightning, these fields are not effective for accelerating particles on their own, because they oscillate transversely. In contrast, when an ultraintense pulse of light strikes a plasma (a gas of electrons and positive ions), it propels the electrons forward close to the speed of light, as we described above.

That is not the end of the story. The plasma's positive ions, being thousands of times heavier than the electrons, are left behind. This separation of positive and negative charges produces a large electric field, which can be used to accelerate other particles. The region of high electric field travels through the plasma as a wave, trailing in the wake of the light pulse. Charged particles are accelerated to high energy in laser wake fields just as dolphins gain energy by swimming in phase with the water wave in the wake of a ship. Such a laser wake-field accelerator was first proposed in 1979 by Toshiki Tajima and John M. Dawson, both then at the University of California at Los Angeles.

The process of converting the oscillating electric field of the light pulse into a wake field that points always in one direction

CHIRPED PULSE AMPLIFICATION

THE KEY to tabletop ultrahigh-intensity lasers is a technique called chirped pulse amplification. An initial short laser pulse is stretched out ("chirped") by a factor of about 10^4, for instance, by a pair of diffraction gratings. The stretched pulse has low intensity, allowing it to be amplified by a small laser amplifier. A second pair of gratings recompresses the pulse, boosting it to 10^4 times the peak intensity that the amplifier could have withstood.



JUAN VELASCO

is called rectification, by analogy with rectifiers in electronics that convert alternating current (AC) to direct current (DC). Conventional accelerators, such as the three-kilometer-long one at the Stanford Linear Accelerator Center (SLAC), use metal cavities to rectify radio-frequency waves to repeatedly "kick" charged particles along the beam line. (Radio waves are electromagnetic waves just like light but having much lower frequencies and longer wavelengths.) The Stanford accelerator has to be three kilometers long to achieve its target particle energies because the accelerating field of each cavity is limited. The field could be increased by using radio waves of shorter wavelength and greater intensity, but both of these properties are limited by the cavity: the cavity size limits the wavelength, and high intensities cause electronic breakdown (sparking) of the metal cavity walls. Laser wake-field accelerators avoid these limits by eliminating the cavity. With the highest-intensity pulses, particles might be accelerated directly, the same way that relativistic electrons are generated by the beam, allowing the plasma to be dispensed with.

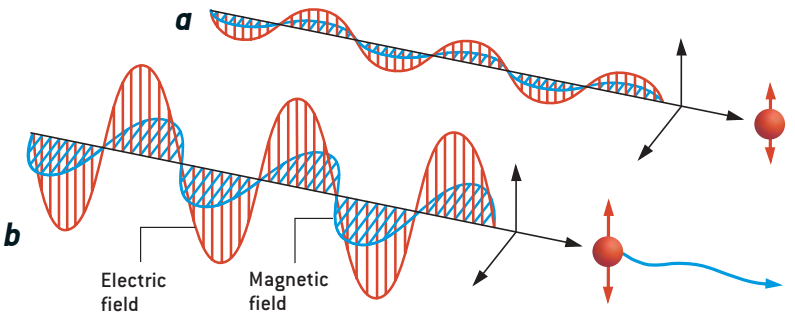
In the past few years, laser-driven electron and proton accelerators have produced beams with energies greater than 50 million electron-volts (MeV), comparable to a single stage (a few meters long) of a conventional accelerator. The laser system achieves the same energy in a millimeter.

Prompt acceleration with high gradients has advantages. For example, one of us (Umstadter) has demonstrated electron beams of a few million electron-volts whose "brightness" (in essence, the concentration of particles in the beam) exceeds that of beams made by conventional accelerators, mainly because the charges bunched in one pulse of the beam have less time to blow it apart by its own electrostatic forces. In addition, researchers have shown that low-cost laser accelerators are suitable for many of the same applications as conventional accelerators, such as producing short-lived radioisotopes used in

LIGHT INTERACTING WITH MATTER

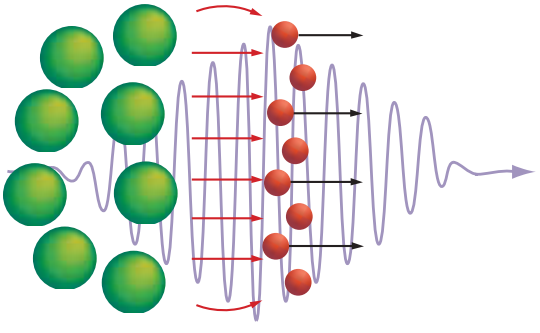
RELATIVISTIC OPTICS

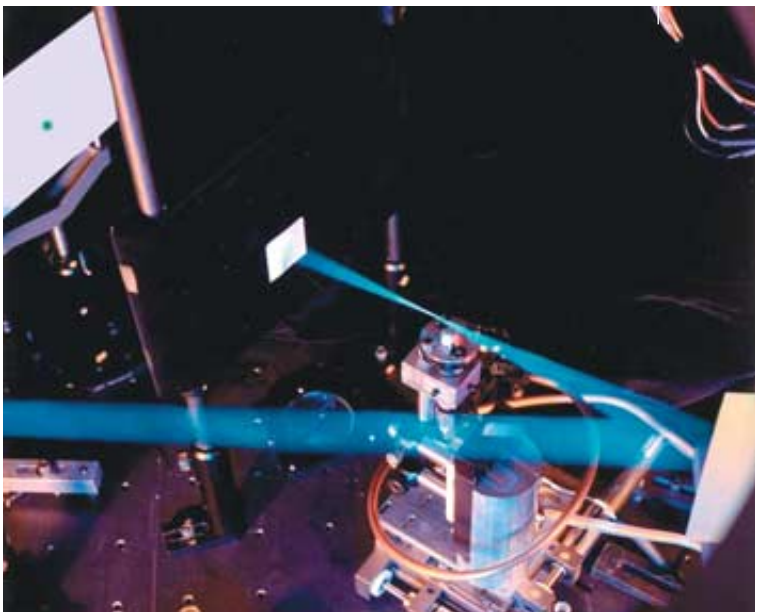
FOR LIGHT of ordinary intensity (*a*), the light's electric field (*red waves*) makes electrons oscillate at relatively low speeds. At extremely high intensities (*b*), the electrons oscillate at nearly the speed of light, and the light's magnetic field (*blue waves*) makes them fly forward with very high momentum.



WAKE-FIELD ACCELERATION

HIGH-INTENSITY LIGHT striking a plasma (*below*) pushes the electrons to very high speeds, leaving the heavier positive ions (*green*) behind and producing a powerful electric field (*red lines*) between these separated charges. This separation of charges and the associated electric field trails along in the wake of the light and can accelerate other charged particles to very high energy.

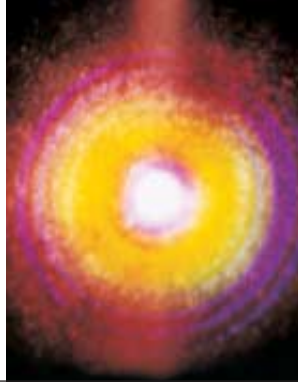




ULTRAHIGH-INTENSITY LASER PULSE (*added in blue*) focused on a jet of helium gas by a parabolic mirror accelerates electrons from the gas to 60 MeV in one millimeter. A fluorescent screen (*upper left*) detects the high-energy electron beam.

NINA FINKEL (*illustrations*); WILLIAM PELLETIER *Photo Services, Inc.*, AND DONALD UMSTADTER, COURTESY OF THE UNIVERSITY OF MICHIGAN (*photograph*)

Small ultrahigh-power lasers might work like spark plugs, igniting thermonuclear fusion at power plants.



medical diagnostics and generating neutron and positron beams for studies of materials.

The laser systems create beams that have a relatively broad spread of particle energies, however, which is undesirable for some applications. Also, conventional systems routinely chain together numerous accelerator stages, as in SLAC's three-kilometer collider and the seven-kilometer-circumference main ring of the Tevatron at Fermilab. Current research on laser accelerator systems is concentrated on reducing the beam's energy spread and achieving multistaging to increase the beam's energy. Researchers are also exploring the use of waveguides to increase the distance over which the wake field keeps accelerating particles.

The High-Energy Frontier

WE DON'T EXPECT laser accelerators to replace conventional accelerators at high-energy particle physics facilities such as the Tevatron. Rather they complement and augment present-day systems and have characteristics that make them useful for specific applications and new types of experiments. One such niche could be acceleration of unstable particles.

The Tevatron represents the high-energy frontier today: colliding protons with energies of a TeV. Its successor, CERN's Large Hadron Collider, will also use protons. Such collisions are very complicated and messy because protons are agglomerations of strongly interacting particles called quarks and gluons. Electrons and positrons have a more elementary structure than protons and consequently produce much "cleaner" collisions, which allow more detailed, higher-precision studies. But accelerating them runs into a problem: the lightweight electrons and positrons lose too much of their energy to so-called synchrotron radiation as they travel around the curves of a circular accelerator.

One solution will be to accelerate muons, which are 200 times as heavy as electrons and thereby suffer synchrotron losses a billion times lower. Unfortunately, muons are unstable and decay in just over two microseconds on average. High-intensity lasers could be used to accelerate muons very close to the speed of light in a fraction of that fleeting lifetime. At that point, relativistic time dilation helps out, extending the muons' lifetime in proportion to the energy achieved, providing more time for a conventional accelerator to take over. The benefit of prompt laser acceleration would be even greater for particles such as pions, which decay in a mere 26 nanoseconds on average.

Another new type of particle physics experiment enabled by ultrahigh-power lasers is the gamma-gamma collider. Gamma rays are extremely high energy photons or, equivalently, extremely high frequency light—beyond x-rays on the spectrum. A high-power laser beam colliding with a high-energy electron beam produces a narrow beam of gamma rays. In essence, the laser's photons rebound off the electrons in a process called Compton scattering. The energy of the gamma rays depends mostly on the energy of the electron beam: a 250-giga-electron-volt (GeV) electron beam knocks the photons from around 1 eV (visible light) to about 200 GeV.

When two such gamma-ray beams collide, the interactions are even cleaner than electron-positron or muon-antimuon collisions. The process is the reverse of matter-antimatter annihilation, in which particles merge and become a flash of radiation: instead pairs of particles and antiparticles burst into life out of a clash of photons. Only with ultrahigh-intensity lasers, however, are there enough photons in each pulse to produce a significant number of gamma-gamma collisions. In 1997 researchers from the University of Rochester, Princeton University, the University of Tennessee and SLAC demonstrated a variant of this system and produced electron-positron pairs by colliding gamma rays and laser photons. Today every linear particle collider has plans to conduct gamma-gamma experiments, which complement the research possible with the usual electron-positron collisions.

Finding and Curing Cancer

BY GENERATING highly penetrating radiation such as x-rays or particle beams, laser-driven charged-particle accelerators may also be used for cancer diagnosis and therapy. X-rays, of course, have been a diagnostic workhorse for a century. Conventional x-ray tubes accelerate electrons in an electric field that is set up between a cathode and an anode. When they strike the anode, the electrons are violently decelerated, which produces copious x-ray emissions. The resolution is limited by the size of the x-ray source, in this case the anode, which is generally about 100 microns across. The smallest tumor detectable by such a system is about a millimeter in diameter.

An ultrahigh-intensity laser can produce x-rays simply by being focused onto an appropriate metal target. The beam accelerates electrons near the surface of the metal to high energies. These electrons are decelerated by their passage through the volume of the metal, once again emitting copious x-rays. Focusing the laser to a spot a few microns across makes an extremely small x-ray source, allowing detection of very small clumps of cancerous cells so that treatment can begin at a much earlier stage in a tumor's development. In principle, resolution of a micron—a little larger than the wavelength of the driving laser—is possible. Research groups at Stanford University, Lund University in Sweden and the National Institute of Scientific Re-

THE AUTHORS

GÉRARD A. MOUROU and *DONALD UMSTADTER* were among the founders of the National Science Foundation–sponsored Center for Ultrafast Optical Science at the University of Michigan at Ann Arbor. Mourou, the director of the center, is a professor of electrical engineering, and Umstadter is an associate professor of both nuclear and electrical engineering. When they are not accelerating particles with intense lasers, they can be found accelerating down ski slopes to "ultrahigh" speeds.

RADIOGRAPH OF A RAT shows the very high resolution that can be achieved by using x-rays generated from a tiny spot of plasma at the focus of a tabletop ultrahigh-intensity laser.

search in Quebec have demonstrated these x-ray systems.

Precision is also of great importance for radiation therapy. The goal is to maximize the dose delivered to the tumor while minimizing harm to surrounding healthy tissues. When treating tumors in such sensitive areas as the brain or the spinal cord, the ability to deposit controlled amounts of energy in small, well-defined areas is critical. Particles such as protons and carbon ions are particularly well suited to this task. Unlike electrons and photons, these heavier particles suffer only minimal lateral scattering, so a beam remains narrow. The particles lose energy at a steady, very low rate along their track and then dump most of their energy at the end of it. For a specific initial energy, this occurs at a well-defined range through the tissue. Consequently, such heavier ions have much better accuracy than electrons and photons for delivering a dose to deep-seated tumors.

Clinical trials using proton and carbon beams are under way in several countries. One of the chief obstacles to wide-scale use of particle-based therapy, however, is the high cost of conventional particle accelerators. For example, the Heavy Ion Medical Accelerator in Chiba, Japan, cost almost $300 million to build. It can treat only about 200 patients a year, a small fraction of cases that could benefit from this form of cancer therapy. At the present time, laser-driven accelerators are able to achieve ion energies that are about a factor of five too low and have too great a spread of energies. But if those two problems can be overcome, ion radiotherapy of cancer will be possible at much lower cost and thus available to many more patients.

A pulse from an ultrahigh-intensity laser delivers as much power as all the world's power generators. In the future, that equation may be turned around, with such lasers becoming an essential component of nuclear fusion power plants *supplying* some of the world's power needs. Controlled nuclear fusion for power generation has been pursued for decades and has remained frustratingly out of reach. A method that has gained favor in recent years is inertial-confinement fusion, in which capsules of fuel—such as mixtures of deuterium and tritium (heavy isotopes of hydrogen)—are hit from all sides simultaneously by dozens or hundreds of intense laser pulses. The lasers compress and heat the capsules to the extreme densities and temperatures at which the deuterium and tritium nuclei fuse together to form helium and release large amounts of energy. The huge Nova laser at Livermore was one of the leading experimental devices used in research toward that goal.

Tabletop ultrahigh-intensity lasers cannot supply enough total energy to drive thermonuclear fusion, but in conjunction with their Nova-size cousins, they may bring the process much closer to economic and technical feasibility. Achieving the conditions needed to ignite fusion by compressing the capsules requires an extraordinarily symmetrical implosion process. The tiniest imperfections lead to worthless fizzles. In the new technique, proposed by researchers at Livermore, the large lasers will still do the hard work of compressing the fuel to high density but do not have to achieve the full ignition temperature as well. Instead, near the point of maximum density, an ultrashort pulse of ions accelerated by a compact, ultrahigh-power CPA laser strikes the imploding capsule, playing a role like a spark plug in a car engine: the pulse creates an intense hot spot, igniting a wave of fusion that burns across the rest of the pellet. This technique should reduce the immensely difficult technical requirements of igniting fusion by implosion alone, and it should significantly increase the ratio of energy produced to energy used.

Some of the fundamentals of the fast-ignition technique were recently demonstrated by researchers from Rutherford Appleton Laboratory in Oxfordshire, England, and Osaka University in Japan. But as is always the case in fusion research, much more must be accomplished to prove the method's practicality for economic power generation. Whether or not that particular application becomes the stuff of legend, ultrahigh-intensity light has a future that is spectacular and diverse beyond the wildest dreams of Archimedes and Diocles. SA

MORE TO EXPLORE

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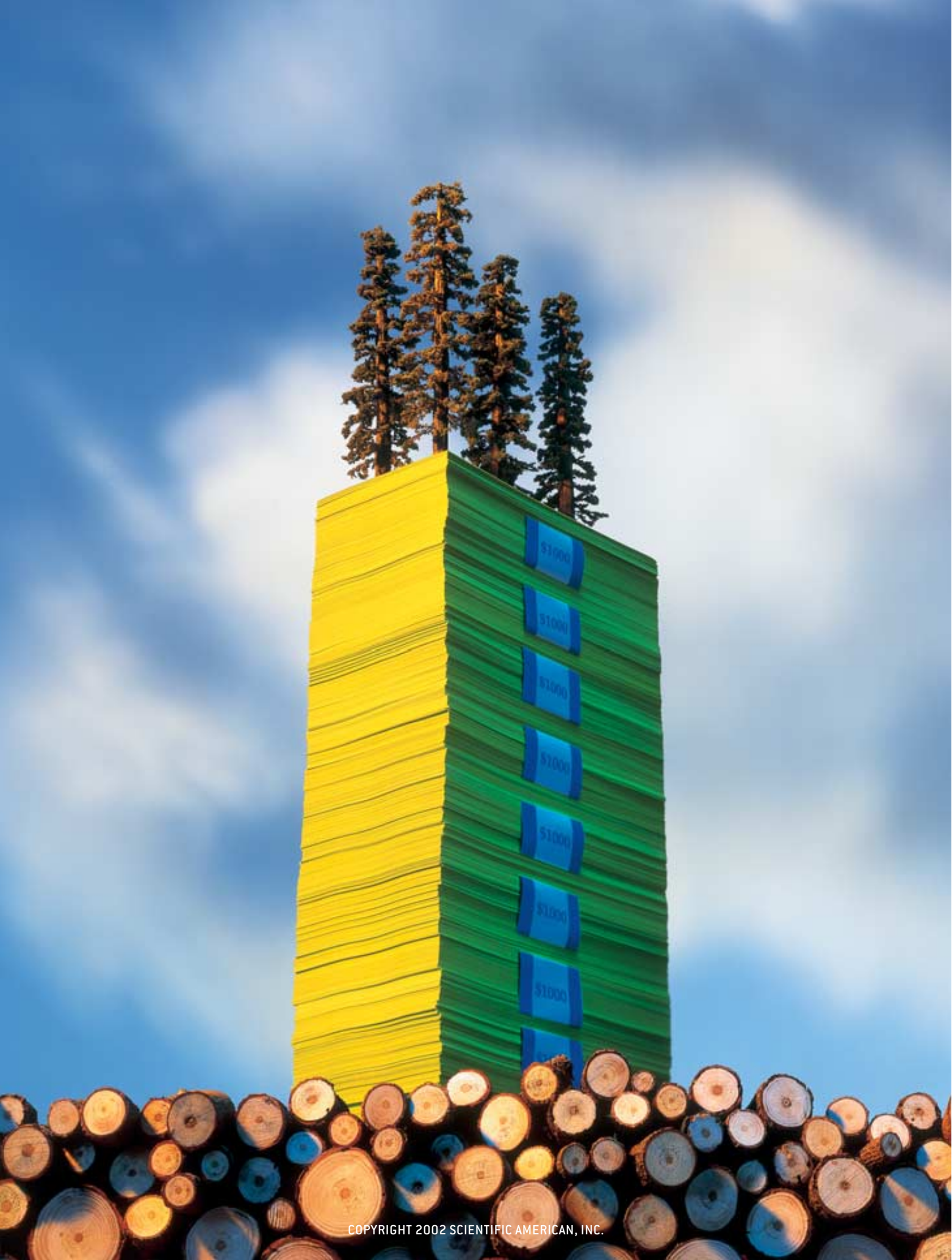
High Field Science Research at the University of Michigan Center for Ultrafast Optical Science: **www.eecs.umich.edu/USL-HFS/**

COURTESY OF LUND LASER CENTER, SWEDEN



Buying green products won't be enough to save biodiversity in the tropics. A new plan for marketing conservation services may be the answer

Rethinking GREEN CONSUMERISM

By Jared Hardner and Richard Rice
Photographs by Pete McArthur

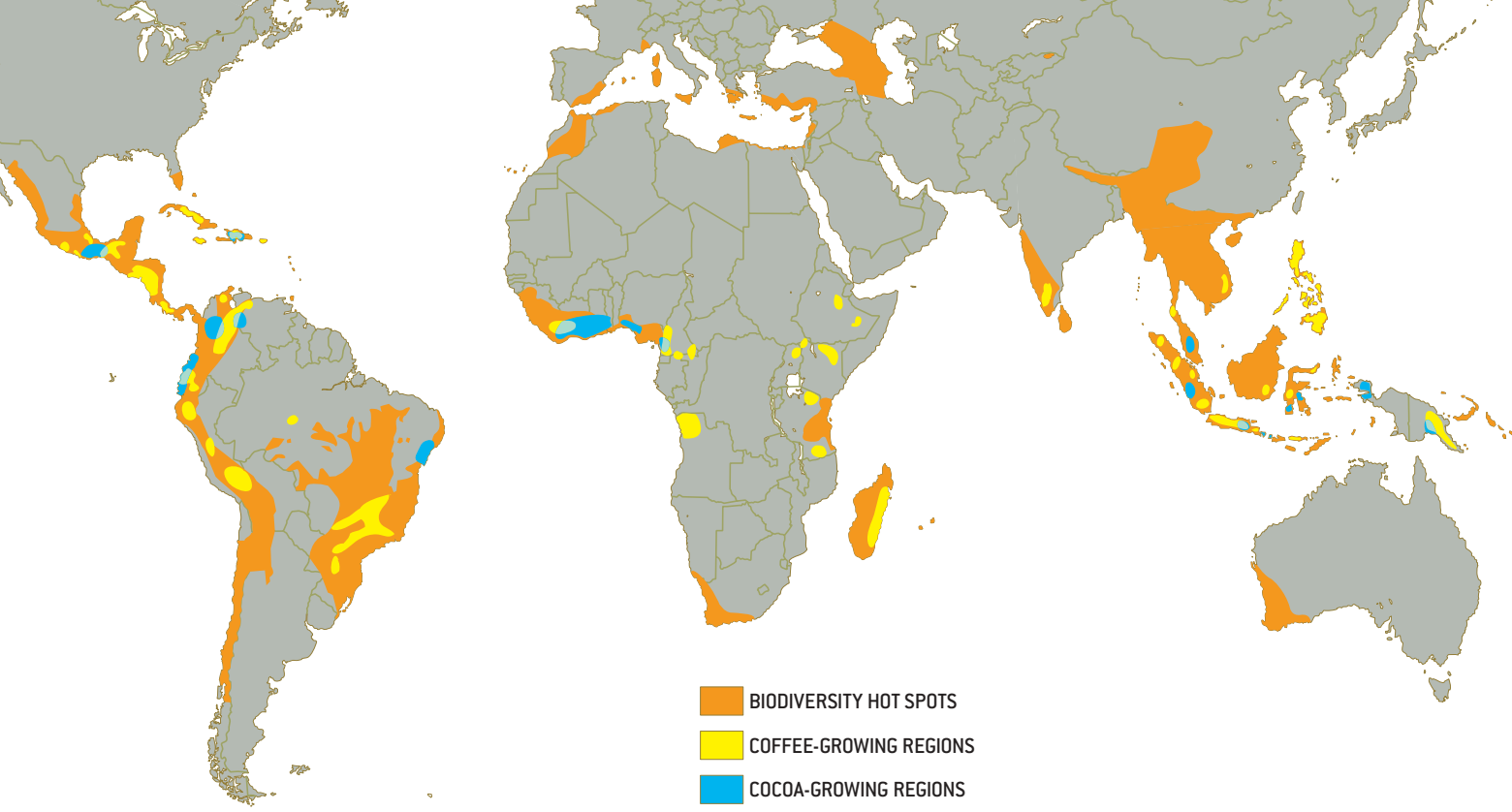
Over the past decade, one popular tropical conservation effort has been to encourage consumers to pay more for products that are cultivated or harvested in ecologically sensitive ways. Myriad international development projects have promoted these so-called sustainable practices in forests and farms around the world. Ordinary citizens in the U.S. and Europe participate by choosing to buy timber, coffee and other agricultural goods that are certified as having met such special standards during production. One of the best known of these certified, or "green," products is shade-grown coffee beans, which are cultivated in the shady forest understory rather than in sunny fields where all the trees have been cut down.

Efforts to develop green products deserve support and praise. But in the context of the global economy, sustainable agriculture and consumer actions alone will not be enough to conserve the plants and animals that are most threatened by deforestation. We believe that a bold new approach, which we call conservation concessions, provides a potentially powerful way to expand the green market from its present dependence on products to the broader notion of green services—the opportunity to purchase biodiversity preservation directly.

The feasibility of this strategy relies on economics. Huge tracts of public forest in the developing world are being leased for less than $1 per hectare a year. At those prices, conservation organizations, which have long demonstrated a willingness to pay for the preservation of biodiversity, can afford to outbid competitors for land leases and to compensate local people to manage the intact ecosystems. These agreements are legally and economically no different from logging contracts or any other business deal that grants control over natural resources to a particular group. Indeed, the income that developing countries can generate in this way is equivalent to, and often more stable than, what they could earn through the volatile international markets for timber and agricultural goods.

No Other Choices

ONE OF THE GREATEST ADVANTAGES of conservation concessions is that they dispel the notion that habitat destruction is inevitable if ecosystems are to generate



CONSERVATION AND AGRICULTURE often compete for the same valuable tracts of land. Major growing regions for coffee and cocoa coincide with some of the world's richest and most threatened areas in terms of biodiversity. Cultivation of these two crops alone has replaced or degraded nearly 20 million hectares of natural habitats in the tropics.

financial benefits. During a study of cocoa economics in Ghana in the spring of 2000, an official in that country's department of forestry explained to one of our research partners, Eduard Niesten, that Ghana's government cannot be expected to set aside more than the 20 percent of its prized high-canopy forest zone that is already protected by national law. The rest must be used for economic progress, the official said. This pessimistic sentiment is widespread among governments and residents of many developing countries, where economic planning often includes rapid growth of the production of agricultural commodities, especially after logging operations have cleared the land. These activities represent an attractive—and perhaps the only—development option in tropical countries, which tend to have an abundance of land and unskilled labor but insufficient capital to finance more costly endeavors, such as industry.

To examine this issue more closely, we formed a research team with six other investigators at Conservation International's Center for Applied Biodiversity Science in Washington, D.C. Our aim was to study agricultural commodities that are produced in areas designated by ecologists as the world's richest and most threatened in terms of biodiversity [*see map above*]. These 25 so-called biodiversity hot spots, which encompass only 1.4 percent of the earth's land surface, have lost at least 70 percent of their primary vegetation. They are also prime habitats for 44 percent of all vascular plant species and 35 percent of all land-dwelling vertebrate species. Based on this three-year study, our team determined that in addition to logging for timber, natural-habitat destruction is rapid and extensive to accommodate the production of five agricultural commodities: beef, soybeans, palm oil, coffee and cocoa.

In the 1980s the expansion of cattle ranches in South America was widely publicized. This activity accounted for 44 percent of deforestation on the continent during that decade. Today one of the greatest threats to South America's tropical biodiversity is the expanding production of soybeans, most of which goes to feed livestock. Since the 1970s soybean cultivation has grown by 13 million hectares in Brazil alone—the fastest expansion of any agricultural product in the tropics known to date. Government subsidies have allowed this activity to move into areas never before touched by agriculture. In neighboring Bolivia, the area devoted to this crop has grown by an average of nearly 35 percent a year since the mid-1960s and is fast approaching one million hectares.

Elsewhere natural forests are being converted at an alarming rate to cultivation of the other three crops in our study. Spread ubiquitously around the world's biodiversity hot spots are coffee and cocoa, occupying 11 and eight million hectares, respectively. Their cultivation has replaced as much as 80 percent of Ivory Coast's original forests. Malaysia leads the production of palm oil, cultivating three million hectares out of the total six million devoted to this commodity globally. Indonesia, which currently grows oil palm on 2.5 million hectares, has vowed to overtake its neighbor as the world's leading producer by planting the 15 million additional hectares that the government has already slated for oil palm plantations.

Certainly the intention of people who convert biologically diverse ecosystems to agriculture or logged forests is to improve their economic lot in life. The sad irony is that these prospects are often unreliable. When countries choose logging and agriculture for lack of better economic options, they often are not competitive in

JANA BRENNING; SOURCE: CONSERVATION INTERNATIONAL

THE LIMITS OF BUYING GREEN

A POPULAR STRATEGY for slowing the destruction of tropical forests has been to promote ecologically friendly practices within the agriculture and logging industries. But demand for coffee, timber and other "green" goods that are produced according to these certified practices originates almost entirely in Europe and the U.S., where consumers are willing to pay premium prices to support conservation. These niche markets play an important role in conservation efforts, but they have serious limits.

Unreliable profits restrict the markets for coffee and cocoa. Whether or not they produce green goods, all cultivators of these products must face the uncoordinated nature of global production, which often results in vast oversupply. Cocoa production swelled throughout the 1980s and 1990s, for instance, despite a punishing decline in price. For green consumerism to work in this context, conservationists must find ways not only to make cultivation and harvesting ecologically sound but also to ensure that the products will be profitable in a competitive global market.

A different problem confines the market for green timber. Organizations such as the Mexico-based nonprofit Forest Stewardship Council have certified more than five million hectares of logging activity in Asia, Africa and Latin America. The problem is that almost all the green timber produced in these forests is sold in Europe and the U.S., which together import less than 6.5 percent of the 228 million cubic meters of all timber—green or otherwise—that is produced in the tropics every year. The vast majority of uncertified logging serves the economies outside these regions.

The worse-case scenario occurs when uncertified logging occurs in biodiversity hot spots such as Madagascar, where most of the timber harvested will become charcoal that local people burn for fuel. This island country, which is less than 2 percent the size of neighboring Africa, harbors a staggering diversity of living things that are found nowhere else on the planet, including at least 8,000 species of flowering plant. Madagascar shelters 12 percent of all living primate species, 36 percent of all primate families, and 33 species of lemur that exist virtually nowhere else, making it possibly the world's single most important area for conservation of these animals. And yet because the trees are consumed domestically, wealthy foreign consumers looking to "buy green" have no opportunity to influence the logging of these priceless forest habitats.

—J.H. and R.R.

A NEW GREEN MARKET

LAND SET ASIDE FOR CONSERVATION is often deemed an economic asset gone to waste. A new market for green services promises to eliminate this trade-off. International willingness to pay for conservation reflects growing demand for protection of the world's biodiversity, which many developing countries can readily supply. The logic behind this new market is simple: landowners lease natural resources to conservationists, who pay the same as or more than logging companies or other destructive users. These so-called conservation concessions not only protect the land but also finance conservation services and provide employment for local people. A properly executed conservation concession:

ENABLES HOST COUNTRIES TO CAPITALIZE ON THEIR AMPLE SUPPLY OF BIODIVERSITY-RICH HABITATS. The concession approach alleviates economic reliance on volatile timber and agricultural commodity markets and allows tropical countries to benefit economically by protecting their natural resources. This benefit can be achieved without depreciating the value of the natural resource and without damaging wildlife habitats or other aspects of the environment.

STIMULATES ECONOMIC DEVELOPMENT BY MIMICKING THE PAYMENT STRUCTURE OF OTHER BUSINESS TRANSACTIONS. Payments cover government taxes and fees, lost employment, and capital investment and are made in hard currency. Part of these fees is directed to the local communities to create jobs and invest in social programs.

OFFERS IMMEDIATE, TRANSPARENT PROTECTION FOR THE LAND IN QUESTION. The tangible nature of conservation concessions offers a clear way to quantify the payoff of biodiversity investments. They should also appeal to corporations seeking methods to offset the environmental impacts of their operations with unambiguous benefits.

CATALYZES CONSERVATION IN SITUATIONS WHERE CREATING A NATIONAL PARK MAY BE INFEASIBLE. Conservation concessions provide governments with an economically sound motive for creating protected areas that extend beyond park systems. Concession payments also ensure long-term management of these areas, in contrast to many underfunded national parks.

REDUCES RISK OF FAILURE BY ESTABLISHING ONGOING ECONOMIC INCENTIVE FOR COOPERATION. Substantial financial risk accompanies business investments in many developing countries, but a well-constructed incentive system based on annual payments in return for resource monitoring and other conservation services should dramatically reduce the temptation to break a concession agreement.

—J.H. and R.R.

global markets. Indeed, the very nature of export commodity markets is that many producers are not profitable for years at a time because of chronic oversupply. The annual harvest of cocoa and accumulated stocks, for example, exceeded consumption by between 30 and 70 percent each year from 1971 to 1999. Cultivators in West Africa recently resorted to burning their crops in a desperate protest of the situation. Another striking example played out in Bolivia, where in 1996 the imposition of a new tax of $1 per hectare on the country's 22 million hectares of timber concessions resulted in nearly 17 million hectares being abandoned by loggers. In other words, the potential net returns for logging these forests were so low that an additional cost of $1 per hectare per year was enough to make most companies avoid these investments.

No matter the level of economic payoff, all these situations can portend widespread, irreversible loss of biodiversity. The concept of sustainable forestry and farming practices was born of this dilemma—the need to promote economic development while mitigating its probable course of ecological destruction. But our recent studies have convinced us that attempting to give green consumers broader access to agricultural markets is not necessarily a winning option for economic development or conservation in many settings. The share of the global agricultural market that is occupied by green goods is largely limited to those consumers in Europe and the U.S. who have the money for, and an interest in, purchasing such products. This reality effectively eliminates the potential for curtailing deforestation related to many agricultural products—for example, soybeans from Brazil that are eaten by livestock, oil palm in Indonesia that is cultivated for domestic consumption, and trees in Madagascar that are burned locally as fuel [*see box on page 91*].

Even when certified goods—such as coffee, timber and beef—do reach wealthy consumers, the effect is not as significant as some may think. Less than 1 percent of the coffee imported into the U.S. is certified for social or ecological reasons. What is more, most of the land newly devoted to growing coffee beans is for robusta, usually sold in developing countries as instant coffee, rather than arabica, the product sold most commonly in cafés of the industrial world. Green timber fares no better. Even if every board foot of wood imported into the U.S. and Europe from tropical countries were certified, it would make up only 6.5 percent of total production from the tropics. The rest is being sold in regions where consumers have little or no interest in certified timber. Similarly, organically produced beef is growing in popularity in industrial countries. But international trade in beef represents only between 1 and 3 percent of global production; in the developing world, beef production is growing at more than 3 percent a year, primarily to serve domestic markets.

Marketing Green Services

THE MORE WE STUDIED the conservation impacts of timber and agricultural commodity markets, the more convinced we became that attempting to support these markets through price premiums for green products is not the only way to encourage conservation. This situation seemed especially tragic when we considered the high demand for biodiversity protection among the international community. A common misperception is that conservation cannot compete directly with most other economic uses of natural resources; in reality, the conservation economy is quite large. The international community—including governments, multilateral development banks and conservation groups—spends at least half a billion dollars annually on biodiversity conservation in the tropics.

This figure is only a small fraction of the global budget that could be directed to biodiversity-rich countries if better investment mechanisms existed. In 1999 an example from Bolivia showed us just how far these financial resources can go. That year Conservation International paid a logging company $100,000 to retire its 45,000-hectare timber concession. As part of the deal, the Bolivian government agreed to integrate the area into adjacent Madidi National Park. Bottom line: an area three times the size of Washington, D.C., received permanent protection for less than the average price of a house in that city.

Working with timber concessions or other lease arrangements enables conservationists to avoid the problems associated with purchasing land outright. Some governments balk at the idea of foreign investors taking permanent control of parts of their territories, especially if they are trying to ensure a renewable stream of revenue from their natural resources. For the same reasons, incorporating land into national parks—as conservationists were able to convince the Bolivian government to do—is also a rare opportunity. That is why the Bolivia experience, and others like it, inspired us to take advantage of the low prices for which millions of hectares of forest could be leased in the tropics.

We developed the conservation concession approach to leasing land with several major goals in mind [*see box on opposite page*]. Most important, perhaps, was that a portion of the concession payments would be directed to local communities to support employment and social services. In the same way that a logging company would pay local residents wages

THE AUTHORS

JARED HARDNER and *RICHARD RICE* have collaborated on economic studies of biodiversity conservation in South America, Africa and Asia for the past 10 years. Hardner earned a master's degree in natural resource economics from Yale University in 1996, and four years later he co-founded Hardner & Gullison Associates, an environmental consulting firm based in Palo Alto, Calif. Rice received both a master's degree in economics and a doctorate in natural resources from the University of Michigan in 1983. In 1992 he joined Conservation International (CI), and in 1999 he accepted his current position as chief economist of the organization's Center for Applied Biodiversity Science in Washington, D.C., where Hardner also serves as a research fellow. The authors would like to express their thanks to collaborators Anita Akella, Gregory Dicum, Philip Fearnside, Sharon Flynn, Ted Gullison, Chris LaFranchi, Michelle Manion, Shelley Ratay, the staff of CI's offices in Guyana and Peru, and the staff of ProPetén in Guatemala.

PARTNERING WITH PARKS

NATIONAL PARKS are an important component of any nation's conservation plan. In countries such as Guatemala and Indonesia, conservation concessions can extend the protection that parks offer, especially in areas that allow economic activities such as logging.

GUATEMALA

CONSERVATION CONTEXT: In 1990 the government of Guatemala created the two-million-hectare Maya Biosphere Reserve (MBR). The reserve includes a multiple-use area where commercial exploitation of forest resources is allowed, but its core zones are protected against all activities other than those judged to be environmentally benign, such as scientific research and ecotourism.

WHAT'S AT STAKE: The MBR is the largest remaining tropical forest in Guatemala, and it constitutes a major part of a Mesoamerican biological corridor that shelters the jaguar and other species with extensive ranges.

THE THREAT: Commercial logging (especially for mahogany) and agricultural invasion threaten forests in the multiple-use zone.

PROPOSED CONCESSION: Later this year Conservation International and its Guatemalan partner, ProPetén, hope to finalize conservation-concession contracts with the communities that manage some 75,000 hectares of forest within the multiple-use zone. These additional conservation areas will begin to provide habitat links between the reserve's core zones of Tikal and El Mirador national parks.

INDONESIA

CONSERVATION CONTEXT: Siberut National Park protects just under half of the 400,000-hectare island of Siberut, off the western coast of Sumatra. Only about 60 percent of the 205,000 hectares outside the park remain naturally forested.

WHAT'S AT STAKE: Three distinct types of forest habitat, including lowland tropical rain forest and freshwater swamp, support a diversity of life. Four of the island's primate species—Kloss gibbon, pig-tailed langur, Mentawai langur and Mentawai macaque—live nowhere else in the world. About 35,000 Mentawaian people, who maintain a Neolithic social structure, also rely heavily on the island's forest resources for their subsistence.

THE THREAT: Pending concessions for commercial logging and oil palm plantations threaten 80 percent of the island—including areas within the park.

PROPOSED CONCESSION: The local government of Siberut and Conservation International are negotiating a conservation concession that could extend the area protected by the park and curtail encroachment by logging and agriculture. *—J.R. and R.R.*

and benefits to work in the mills, the financier of the conservation concession would hire them to preserve the forest.

Once we had developed a clear set of criteria for this newfangled green services market, we set off to create a series of pilot conservation concessions. Among the first countries we visited, early in 2000, was Peru. There we planned to compete for part of the 800,000 hectares of Amazon forest that the government was putting up for lease in an international auction. What transpired during our negotiations confirmed our theory that the economic value of forest resources in Peru—and many other regions of the world—is poor at best. Indeed, the auction began with a proposed minimum bid of between $1 and $4 per hectare a year and involved forestry companies from Europe and North and South America in addition to us. In a matter of months, however, the auction was called off because the other potential bidders lost interest in these concessions, presumably because the base price was too high. The fate of that particular forest remains to be determined, but we had planted a seed that took root in the fertile ground prepared by the Peruvian conservation community.

Peru had been undergoing the final revisions of its forest and wildlife law, a process in which several conservation groups were seeking alternatives to logging leases for Peru's forests. In April 2001 the government chose to include conservation concessions as a legal use of its 67 million hectares of public forest. We had entered the original bidding arena without knowing for certain that we would be allowed to compete, so this was good news. At around that time, a Peruvian conservation group, the Amazon Conservation Association, approached us. The group's members wanted to use a conservation concession to secure critical natural habitat where they were setting up an ecological research station. Under the new Peruvian law, concessions could be acquired by applying for specific areas of interest to the bidder. We leaped at the chance to help launch Peru's first conservation concession.

Thanks to the scientific and community work of the Amazon Conservation Association, legal advice from the Peruvian Environmental Law Society (SPDA), assistance from independent environmental consultant Enrique Toledo, and the enthusiastic support of Peru's Minister of Agriculture, Carlos Amat y Leon, Peru established the Los Amigos conservation concession in July 2001. The agreement centered on a renewable 40-year lease for the conservation management and study of 130,000 hectares of tropical forest. This land forms part of an ecological corridor that links Manu and Bahuaja-Sonene national parks in Peru and protects many of that country's 25,000 species of flora and 1,700 species of birds.

Catching On

OVER THE COURSE of our Los Amigos negotiations, we also conducted discussions for pilot projects in Guyana and Guatemala. In September 2000 the government of Guyana issued to Conservation International an exploratory permit for a conservation concession of approximately 80,000 hectares in the southern part of the country. During the subsequent months, we have worked with forest commission officials to negotiate the terms of a renewable 25-year contract. We hope to conclude the deal for this uninhabited area of forest later this year.

In Guatemala the national government had already issued timber concessions within the country's two-million-hectare Maya Biosphere Reserve to local communities. These people, who live within the reserve's multiple-use zone, where logging and other economic activities are permitted, are currently producing certified green timber from their forests. Two communities, however, have proposed to forgo logging and instead lease standing trees—and the obligation to protect the ecosystem in which they reside—to conservationists. The communities, together representing about 110 households, could use their new revenue stream from the proposed concession deal to pay salaries for conservation managers, to invest in projects such as guiding tourists to nearby archaeological sites, and to provide community social services such as education and health care. The proposed concessions, which would preserve both pristine forest and a wealth of Mayan ruins, span approximately 75,000 hectares bordering a national park [*see box on opposite page*]. The Guatemala and Guyana deals, both developed and financed by Conservation International's Center for Applied Biodiversity Science and the Global Conservation Fund, represent two very different settings for concessions.

At many turns in our negotiations over the past two years, we have faced scrutiny and skepticism about conservation concessions, from governments and conservationists alike. But the bold actions that some governments, together with significant financial supporters, have taken to adopt this approach indicate that it is viable both as an economic alternative and as a conservation tool.

And the idea is catching on. Last year we received a phone call from a man in Ecuador who had traveled six hours to the nearest international phone line so he could ask about establishing a conservation concession in his coastal forest community. Halfway around the world we struck up a partnership with a small nongovernmental organization in Indonesia that is keen to experiment with this concept as a way to protect that nation's fragile marine ecosystems.

Now, along with other colleagues, we are looking at the feasibility of conservation concessions across Africa, Asia and Latin America, and we predict that this approach will transfer readily to many areas. If we are right, conservation concessions may indeed be able to bring to life a global market for green services. SA

MORE TO EXPLORE

Can Sustainable Management Save Tropical Forests? Richard E. Rice, Raymond E. Gullison and John W. Reid in *Scientific American,* Vol. 276, No. 4, pages 44–49; April 1997.

Biodiversity Hotspots for Conservation Priorities. Norman Myers, Russell A. Mittermeier, Cristina G. Mittermeier, Gustavo A. B. da Fonseca and Jennifer Kent in *Nature,* Vol. 403, pages 853–858; February 24, 2000.

Effectiveness of Parks in Protecting Tropical Biodiversity. Aaron G. Bruner, Raymond E. Gullison, Richard E. Rice and Gustavo A. B. da Fonseca in *Science,* Vol. 291, pages 125–128; January 5, 2001.

Trees of the Triassic

IN THE PAINTED DESERT OF ARIZONA, A STORY OF HOW FORESTS TURNED TO STONE AND HOW THE STONES ARE WALKING AWAY **BY MARGUERITE HOLLOWAY**

PHIL SCHERMEISTER *Corbis*

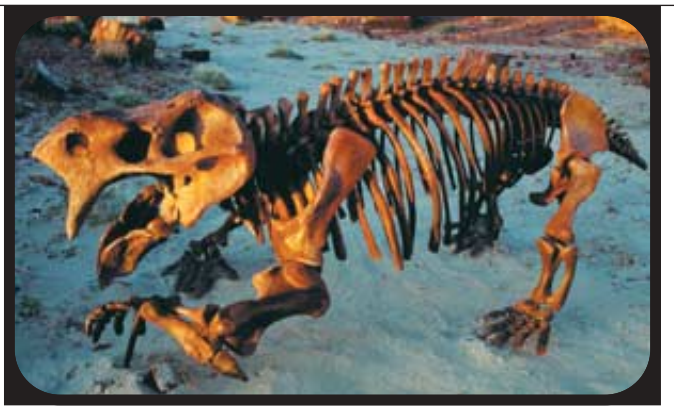
CHINLE FORMATION sediments that make up the Painted Desert were deposited during the end of the Triassic Period. Tall trees such as *Araucarioxylon arizonicum*—a relative of today's star pine—flourished then. Their fossilized remains, often cracked by the land's uplift, can be seen throughout Petrified Forest National Park.

The land and its trees are yellow, pink, putty, purple, periwinkle, orange, gray, lichen green and the green of young grass. White, too, if there is a sprinkling of snow. And the colors, those of the land at least, are always changing—flat in midday, deep and glowing at sunrise and sunset. But the trees are unchanging, stranded on mesas or hillsides or washes, broken and beautiful, made of stone.

The Painted Desert is part of Petrified Forest National Park in Arizona, and both are part of a landscape that today is sere and denuded but that 225 to 220 million years ago was lush and swampy, thick with towering conifers and busy with crocodilelike creatures and small dinosaurs. When the trees fell, they were buried under mud, and over millions of years silica from volcanic ash percolated through the water and covered and then hardened them.

Other minerals also became part of these petrifying trees; some of them have streaks of green from chromium, red and yellow from iron, and blue from cobalt that become especially clear when the stone is polished by machine, as the trees on display in the park museum have been.

The 93,533-acre park is the only one in the park service system that offers visitors such a complete view of life in the late Triassic, a time when dinosaurs were coming to power, overtaking slow and low-to-the-ground, four-legged reptiles.



FOSSILS—such as *Placerias,* a low-lying reptile that was about to be displaced as the Age of Dinosaurs dawned—are on display in the park's museum.

JONATHAN BLAIR *Corbis*

"It was one of the greatest turnovers, changes, revolutions in life on land," says Adrian P. Hunt, director of the New Mexico Museum of Natural History and Science. "It is the most important place on earth where we have all the rocks in one place and lots of fossils to study this transition."

The fossils from the Painted Desert, which lies in the northern section of the long, thin park, and from Petrified Forest to the south, have been pivotal in describing Triassic flora and fauna—the ferns and horsetails, horseshoe crabs and snails, sharks and phytosaurs (the crocodilelike creatures). Perhaps the best-known find is "Gertie," a mysterious two-meter-long dinosaur now classified as a *Chindesaurus bryansmalli.* "It is a very, very special place paleontologically," notes Vincent L. Santucci, a chief ranger and, as he puts it, the National Park Service's only "pistol-packing paleontologist."

Pistol packing may seem superfluous in this softly colored landscape, but some expressions of authority are clearly needed in the park. The very things that make seeing the fossilized trees so exciting—their beautiful colors, their history and, as rock-hard, once-soft substances, their embodiment of paradox—have endangered them. More than 12 tons of petrified wood leave the park every year in people's pockets, trunks and backpacks. According to research by Carolyn J. Widner of Humboldt State University and Joseph Roggenbuck of Virginia Polytechnic Institute and State University, just 1.2 percent of visitors remove wood—but that means that 9,600 pieces of wood, at absolute minimum, are lost annually.

Petrified Forest National Park is in danger of disappearing, of going the way of Fossil Cycad National Monument, the only park the U.S. government ever decommissioned because visitors walked off with it. Fossil Cycad was established in 1922 in South Dakota. In 1933, ac-

cording to Santucci, who co-authored a paper on the lost park, the Chicago World's Fair requested a cycad fossil to display, but there was none to be found. The national monument was finally dissolved in 1957. "We use Fossil Cycad as an example of what is happening to Petrified Forest," says Santucci, who was a ranger at the park in the early 1990s and is now stationed at Fossil Butte National Monument in Wyoming. Santucci says part of the problem is that commercial fossil gathering has become even more lucrative in the past two decades.

The park employs several strategies to combat theft—fines, signs and fencing being the most traditional. But perhaps the more powerful enforcement tool is what is called "conscience wood." In the park's Rainbow Forest Museum at the south entrance, there is a fascinating display of letters from people dogged by ill luck or just sincerely sorry about removing the petrified wood. "I stole them in 1981 and have been and always will be sorry that I distorted your incredibly beautiful park," one letter reads. Others chronicle runs of bad luck after stealing wood: driving accidents, occupational accidents, lost jobs. And another describes a lineage of guilt. It accompanied a piece of wood that had been taken in 1953 during a cross-country trip. The author—who was 11 at the time—remembered his aunt stealing the stone and lying to a ranger as she left the park. After she died in Sweden, he found the fossil in her belongings and sent it back to the park in 1992.

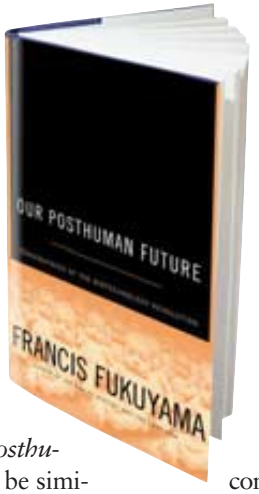
Many people become overwhelmed with guilt, but it is too late. Every week stones are returned by mail, but there will never be enough to balance what is taken. And in any event, a stone never really comes home. "It's been removed from its story," says Karen Beppler-Dorn, chief of resource management. Out of its geologic context, it can no longer speak about the kind of tree that came to rest on a certain spot or why or what that location says about how the water flowed and what the landscape looked like. "Most of what is to be learned about the history of life is yet to be discovered," Santucci says. But only if people leave the stones alone.

Information about Petrified Forest National Park can be found on the Internet at www.nps.gov/pefo, and the geology and fossils found in various national parks are described at www.aqd.nps.gov/grd/parks/pefo/index.htm and www2.nature.nps.gov/grd/geology/paleo. The park usually opens at 8 A.M., and visitors must be on their way to one of the exits by 5 P.M.; there are longer hours during the summer. The north entrance is on Interstate 40 between Holbrook and Navajo, and the south entrance is on U.S. Highway 180. For additional details, call 928-524-6228. SA

Meddling with Human Nature

THE POLITICAL OUTCOMES OF BIOTECHNOLOGY **BY DANIEL J. KEVLES**

OUR POSTHUMAN FUTURE: CONSEQUENCES OF THE BIOTECHNOLOGY REVOLUTION
by Francis Fukuyama
Farrar, Straus and Giroux, New York, 2002 ($25)



In *The End of History and the Last Man,* Francis Fukuyama argued that history was over because the world was converging toward societies of democratic capitalism. The book's thesis, much disputed when it was first published as an article in 1989, seems all the more dubious in the wake of September 11. Now, in *Our Posthuman Future,* a volume likely to be similarly contested, he claims that biotechnology has brought about "the recommencement of history." By that he means that the biotechnological manipulation of human beings may well "move us into a 'posthuman' stage of history"—change human nature in ways that erode the foundations of the putative convergent political order.

Fukuyama brings to this exploration considerable philosophical knowledge, including a manifest respect for Nietzsche, a quotation from whom heads many of the book's chapters. He has also done a lot of homework on biotechnology, absorbing the debates about it, especially its application to human beings. *Our Posthuman Future* is repetitious, salted with questionable judgments and made somewhat confusing by several contradictory claims. It nonetheless sweeps the reader along by the provocativeness of its arguments and the originality of its linkages between the biotechnological and political futures.

Fukuyama's thesis is premised on the contention that there *is* a recognizable human nature. He takes that to be "the sum of the behavior and characteristics that are typical of the human species, arising from genetic rather than environmental factors." The reification of human nature has long been out of fashion among biologists, who recognize the significant contribution of environment to the shaping of human characteristics, and most philosophers, who point to, among other things, the wide variance in values and behaviors across cultures.

Fukuyama responds to such objections partly by deploying some recent claims in neuroscience and behavioral biology: Thus, the brain is not a Lockean blank slate but "a modular organ full of highly adapted cognitive structures, most of them unique to the human species." Thus, cross-cultural universals have been "programmed" into us by evolution, notably our propensity to "parse language for evidence of deceit, avoid certain dangers, engage in reciprocity, pursue revenge, feel embarrassment, care for our children and parents, feel repulsion for incest and cannibalism, attribute causality to events."

Fukuyama fears that, even without changing human nature as such, human genetic engineering could adversely affect our mutually interactive, and hence our political, lives. In one bizarre extrapolation, he delineates the consequences should genetic engineers manage to double the human life span: elderly women would make up a disproportionately large fraction of society, and, being disinclined to support the use of force in international affairs, they would undermine the ability of democracies to defend their interests militarily. Worse, our society would be burdened with a huge cadre of people beyond reproduction or work, retarding social change while they live out an additional three score and 10 years in nursing homes.

But the quotidian consequences of human genetic engineering worry Fukuyama less than its potential threat to human nature, because human nature is fundamental to our notions of justice, morality and any "meaningful definition" of human rights. He contends, for example, that human rights based on our inclination to protect kin rather than strangers provide "a more solid foundation for political order" than those that—so he seems to imply—obligate us to care for, say, welfare mothers or the impoverished peoples in the Third World.

A stable, democratic order also requires respect for an inviolable human dignity, what Fukuyama dubs an essential "Factor X" that distinguishes us from all other animals. Here he seems to contradict himself. On the one hand, he extrapolates from evolutionary studies of animal behavior to argue for the existence of a human nature. On the other, he in-

sists, drawing on Nietzsche, whom he finds a far better guide than today's legions of bioethicists, that we must not admit "a continuum of gradations between human and nonhuman." Such an admission would imply a comparable continuum within the human species and would constitute a justification of undemocratic social ordering, a "liberation of the strong from the constraints that a belief in either God or Nature had placed on them."

Fukuyama is comparably concerned with the potential impact of biotechnology on ineffable human qualities such as individuality, ambition and genius. He finds disturbing harbingers of the direction human genetic modification might take in the uses now being made of the neuropharmacological drugs Prozac and Ritalin. He says, in a seeming caricature of these uses, that the former is often prescribed for depressed women lacking in self-esteem; the latter, largely for young boys who don't want to sit still in class. In his view, the two drugs together are nudging the two sexes "toward that androgynous median personality, self-satisfied and socially compliant, that is the current politically correct outcome in American society." More such drugs are sure to come, he warns, all of them with profound political implications, because they will make deviant behavior into a pathology meriting chemical restoration to a conformist norm.

Fukuyama's biotechnological prognostications are, to say the least, selective, tailored to his alarmism. To play his speculative game for a moment, one can imagine that if genetic engineers can double life span, they could also figure out how to eliminate the differential in longevity between men and women and endow us with full vigor throughout our six score and 20 years. He chooses sociobiological characteristics as constitutive of human nature that are consistent with democratic capitalism, ignoring those—for example, tribalism, submissiveness to authority, and the subordination of women to reproduction—that seem to make large parts of the world decidedly resistant to the freedoms and political structures of the West.

Despite his selectivity, Fukuyama concedes that human biotechnology holds "undisputed promise" and does not want to get rid of it. Yet he is unwilling to leave the biotechnological enterprise to its own devices, fearing, with good sense, that it is too driven by commerce and ambition to exercise self-restraint. In the closing section of his book, he calls for a departure from free-market capitalism in biotechnology—national and international regulation. For starters, the U.S. should follow other countries in banning reproductive human cloning, not primarily because it might be unsafe for the fetus but mainly because if we don't, we will legitimize far more wide-ranging biotechnological manipulations of human beings. "It is important to lay down a political marker at an early point to demonstrate that the development of these technologies is not inevitable," that societies can control the pace of technological advance.

Fukuyama contends that we need institutions with enforcement powers "that will discriminate between those technological advances that promote human flourishing, and those that pose a threat to human dignity and well-being." Apart from cloning, regulation is required for preimplantation diagnosis and screening, germ-line engineering, the creation of human chimeras and the production of new psychotropic drugs. A former member of the State Department (he now teaches international studies at Johns Hopkins University), Fukuyama lays out plausible arguments for how and why such regulation would be practically achievable not only nationally but internationally. His heresy from the religion of free-market capitalism may attract many adherents. They may not be convinced that a posthuman world is really on the horizon, but they are no less disturbed than he by the exercise of untrammeled freedom in human biotechnology. SA

Daniel J. Kevles's works include In the Name of Eugenics *and* The Baltimore Case. *He is a professor in the department of history at Yale University.*

THE EDITORS **RECOMMEND**

THE NEW ECONOMY OF NATURE: THE QUEST TO MAKE CONSERVATION PROFITABLE
by Gretchen C. Daily and Katherine Ellison. Island Press, Washington, D.C., 2002 ($25)

CRADLE TO CRADLE: REMAKING THE WAY WE MAKE THINGS
by William McDonough and Michael Braungart. North Point Press, New York, 2002 ($25)

Be kinder to the environment and make money while doing it. That, seen from different perspectives, is the theme of these books. Daily and Ellison (respectively, a research scientist at Stanford University and an investigative journalist) write of projects that seek "green gold," which means recognizing that ecosystems are capital assets and managing them so that they "continue to yield wealth." Among their examples are New York City's watershed protection program, schemes for turning waste into something useful in Australia and Costa Rica, and a river restoration project in Napa, Calif. McDonough and Braungart (an architect and a chemist) are partners in a firm that creates ecologically intelligent designs for corporations. They argue for a shift from the cradle-to-grave model of manufacturing, in which most of the materials that go into making products end up as waste. They champion a cradle-to-cradle model, in which the materials are "circulated infinitely in industrial cycles … without loss of quality or damage to our environment or ourselves."

The books reviewed are available for purchase through www.sciam.com

Defense in Depth

BY DENNIS E. SHASHA

Imagine a football game played on a six-by-six grid in which a very fast runner starts on the north side of the grid and tries to maneuver past three tackles from the opposite team. Under the rules of this game, the runner's freedom of motion is constricted: he can move only to one of the three grid spaces that are south, southeast or southwest of the space on which he begins. Because he is so fast, however, the runner can make two moves in each turn. The slower tackles can make only one move per turn, but each can move to any adjacent grid space (or simply stay put) [*see illustration A*].

The runner wins the game if he reaches the southernmost row of grid spaces. The tackles win if they block the runner by occupying all the spaces in front of him (the spaces to the south, southeast and southwest). Suppose the runner can begin in any grid space in the northernmost row. After observing the runner's starting point, the three tackles can place themselves in any grid space that is at least three spaces away from the runner. Illustration B shows one possible initial configuration. The runner goes first, making two moves, and then each of the tackles makes one move, and so on. Can either the runner or the tackles guarantee a win? And if so, how?

Now let's change the rules a bit. Let's say that the tackles must start in the southernmost row of grid spaces. A possible initial configuration is shown in illustration C. Under these conditions, can either side guarantee a win? SA

Answer to Last Month's Puzzle

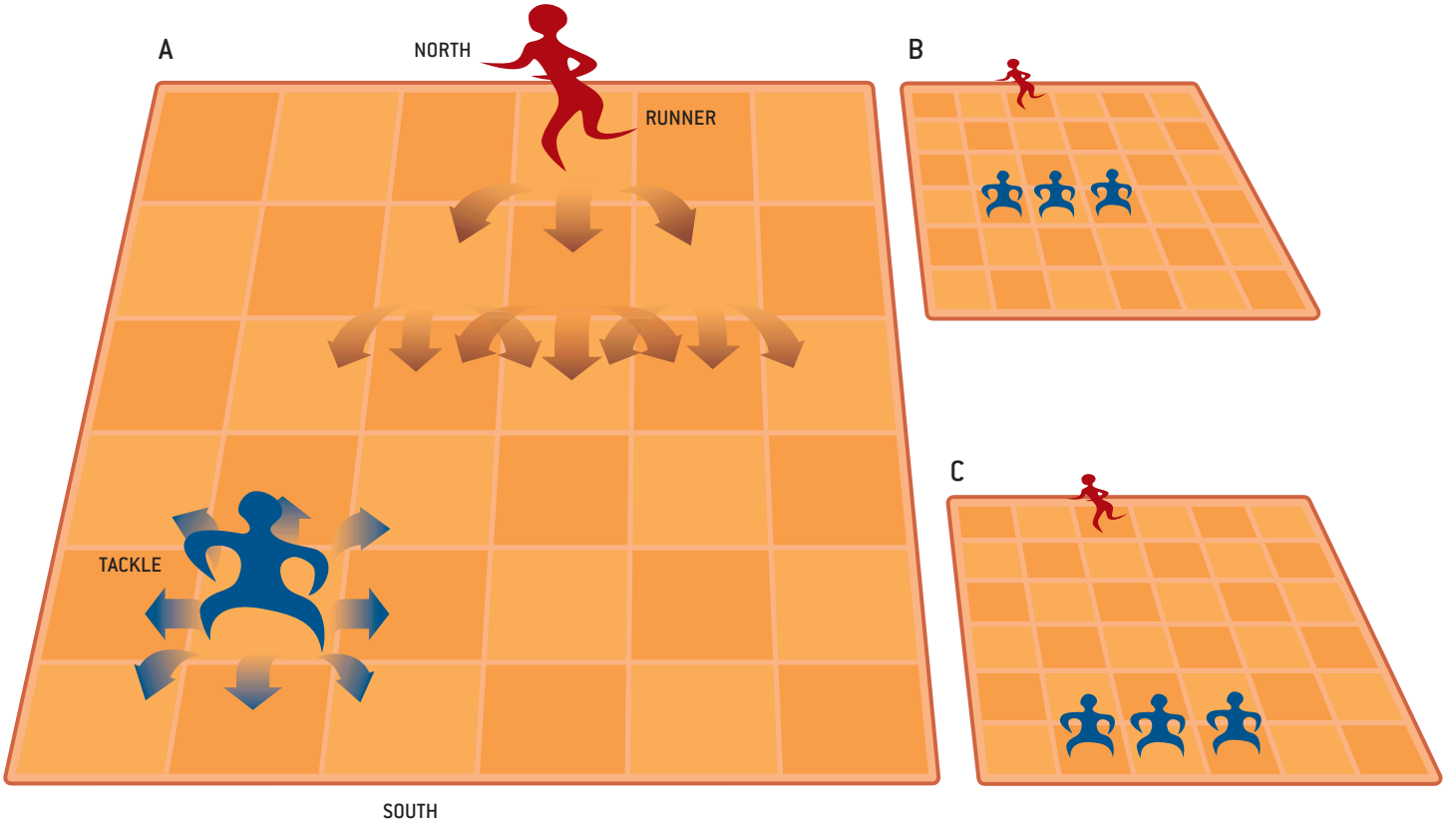
The mythical fairies are attracted to the following colors:

Juliana: turquoise
Katiana: earth
Oliviana: ivory
Anya: sage
Heather: emerald

A full explanation of the solution can be found at www.sciam.com

Web Solution

For a peek at the answer to this month's problem, visit www.sciam.com



SARA CHEN

Cold Comfort

GETTING THE SCOOP ON THE SCIENCE OF A COOL COMMODITY **BY STEVE MIRSKY**

Millennia before the invention of mechanical refrigeration, our ancestors were two for four with their streamlined periodic table of air, water, earth and fire. Because for many of us, the only elements that matter today are the aforementioned air and water (as ice), combined with some fat and a little liquid to produce the thing we all scream for: ice cream.

I learned this short ingredient list while ingesting ice cream information, as well as actual ice cream, during lectures on ice cream science at the annual meeting of the American Association for the Advancement of Science in Boston in February. I already considered myself an expert, thanks to my mentors, Ben and Jerry. But there was still a lot to be learned without inducing an ice cream headache.

For example, the taste for icy sweets predates the technology to mass-produce them; the emperor Nero sent slaves to the mountains for snow and ice to mix with nectar and honey. The resulting ice treat must have been the perfect culinary counterpoint to a baked Rome.

Session speaker Anne Cooper Funderburg, author of *Chocolate, Strawberry, and Vanilla: A History of American Ice Cream,* revealed that the first written record of ice cream in America dates to 1744, when one William Black, secretary to a commission charged with buying land from the Iroquois, wrote that he was served ice cream at the home of the governor of Maryland. Ice cream and contracts with indigenous Americans remained linked by the propensity of both to melt in the heat.

Funderburg further enlightened attendees with this more recent historical sprinkle: the moneymen were leery enough about funding a start-up ice cream operation in frigid Vermont to insist that Ben and Jerry also sell hot soup. Which means that the scrap heap of history may include a label on which appears the now culturally incongruous designation "Ben and Jerry's New England Clam Chowder."

Also on the session menu was H. Douglas Goff, professor of food science at

the University of Guelph in Ontario, where they know from ice. Goff spoke eloquently of "the 3-D fat network," which turned out not to be Fox News. Ice cream by law must contain at least 10 percent milk fat, and a product with less than 10 percent milk fat must be called something else—for example, sherbet. Or chicken. In fact, the creaminess associated with high-quality ice cream is a function of the 3-D fat network, an array of fat globules that gives structural integrity to the entire enterprise of mixed air bubbles, tiny ice crystals and remaining liquid.

Polysaccharides help to check ice crystal growth, which at its extreme makes that half-eaten pint in your freezer look like Superman's Fortress of Solitude. Goff is looking for other substances that, like a hockey referee, might wave off the icing. He's particularly interested in a winter wheat antifreeze protein, which enables the cereal to survive frost. The compound adsorbs to the surface of small ice crystals, stopping their expansion. Numerous animal species also have such antifreezes, but Goff noted that "wheat" on an ice cream's ingredient list would raise fewer eyebrows, and more spoons, than "spider mite."

Merry White, an anthropologist at Boston University, reflected on the global reach and role of ice cream. She pointed out, for instance, that ice cream was sold in Yokohama as early as 1869, which makes it as Japanese as, well, baseball. And with the most popular flavors in Japan actually being vanilla and strawberry, White asked, "Is green-tea ice cream Japanese if you eat it in a cowboy sushi bar in Austin?" I relayed the query to a friend in Austin, who answered, "Yes, if you use chopsticks." My friend may be right, as consumers around the world increasingly impose a cultural identity onto ice cream. After all, White said, "Culture is about choices." She thus inadvertently illustrated the crucial difference between ice cream and frozen yogurt. Because for yogurt, you see, choice is about cultures. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

Q Why do my eyes tear when I peel an onion?

—Patrick Rose, Oakland, Calif.

Thomas Scott, dean of the college of sciences at San Diego State University, provides this explanation:

In this case, tears are the price we pay for flavor and nutritional benefits. The rowdy onion joins the aristocratic shallot, gentle leek, herbaceous chive, sharp scallion and assertive garlic among the 500 species of the genus *Allium*. *Allium cepa* is an ancient vegetable, known to Alexander the Great and eaten by the Israelites during their Egyptian bondage. Indeed, his charges chastened Moses for leading them away from the onions and other flavorful foods that they had come to relish while in captivity. And with good reason: onion is a rich source of nutrients (such as vitamins B, C and G), protein, starch and other essential compounds. The chemicals in onions are effective agents against fungal and bacterial growth; they protect against stomach, colon and skin cancers; they have anti-inflammatory, antiallergenic, antiasthmatic and antidiabetic properties; they treat causes of cardiovascular disorders, including hypertension, hyperglycemia and hyperlipidemia; and they inhibit platelet aggregation.

The tears come from the volatile oils that help to give *Allium* vegetables their distinctive flavors and that contain a class of organic molecules known as amino acid sulfoxides. Slicing an onion's tissue releases enzymes called allinases, which convert these molecules to sulfenic acids. These acids, in turn, rearrange to form syn-propanethial-S-oxide, which triggers the tears. They also condense to form thiosulfinates, the cause of the pungent odor associated with chopping onions—and often mistakenly blamed for the weepy eye. The formation of syn-propanethial-S-oxide peaks about 30 seconds after mechanical damage to the onion and completes its cycle of chemical evolution over about five minutes.

The effects on the eye are all too familiar: a burning sensation and tears. The eye's protective front surface, the cornea, is densely populated with sensory fibers of the ciliary nerve, a branch of the massive trigeminal nerve that brings touch, temperature, and pain sensations from the face and the front of the head to the brain. The cornea also has a smaller number of autonomic motor fibers that activate the lachrymal (tear) glands. Free nerve endings detect syn-propanethial-S-oxide on the cornea and drive activity in the ciliary nerve—which the central nervous system registers as a burning sensation. This nerve activity reflexively activates the autonomic fibers, which then carry a signal back to the eye to order the lachrymal glands to wash the irritant away.

There are several solutions to the problem of onion tears. You can heat onions before chopping to denature the enzymes. You might also try to limit contact with the vapors: chop onions on a breezy porch, under a steady stream of water or mechanically in a closed container. Some say that wearing contact lenses helps. But do not forgo the sensory pleasure and healthful effects of *Allium cepa*.

Q What is the origin of zero?

—Rolf Ebeling, New York City

Robert Kaplan, author of *The Nothing That Is: A Natural History of Zero*, offers this answer:

The first evidence we have of zero is from the Sumerian culture in Mesopotamia, some 5,000 years ago. The Sumerians inserted a slanted double wedge between cuneiform symbols for numbers to indicate the absence of a number in a specific place (as we would write 102, the "0" indicating no digit in the tens column).

The symbol changed over time as positional, or place-sensitive, notation, for which zero was crucial, made its way to the Babylonian empire and from there to India, most likely via the Greeks (in whose own culture zero made a late and only occasional appearance; the Romans had no trace of it at all). Arab merchants brought the zero they encountered in India to the West. After many adventures and much opposition, the symbol we use took hold and the concept flourished. Zero acquired much more than a positional meaning and has played a crucial role in our mathematizing of the world. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert

SRAA CHEN

PHYSICS: THE FINAL EXAM

At dinner, Andy keeps leaning back in his chair. At what angle will he fall over?

Is it possible to pour a one-gallon bottle of orange soda into a twelve-ounce thermos? Why or why not?

What is the fastest speed of rotation that can be attained before someone flies into space?

Based on Laws of Melto-Dynamics, at what time will everything in the refrigerator below be spoiled if it is now 11 A.M.?

According to the Pythagorean Theory of Spillage, how long can a Slurpee and a laptop be adjacent to one another before disaster occurs?

Explain the circumstances under which matter can, and probably WILL, disappear from the Universe.