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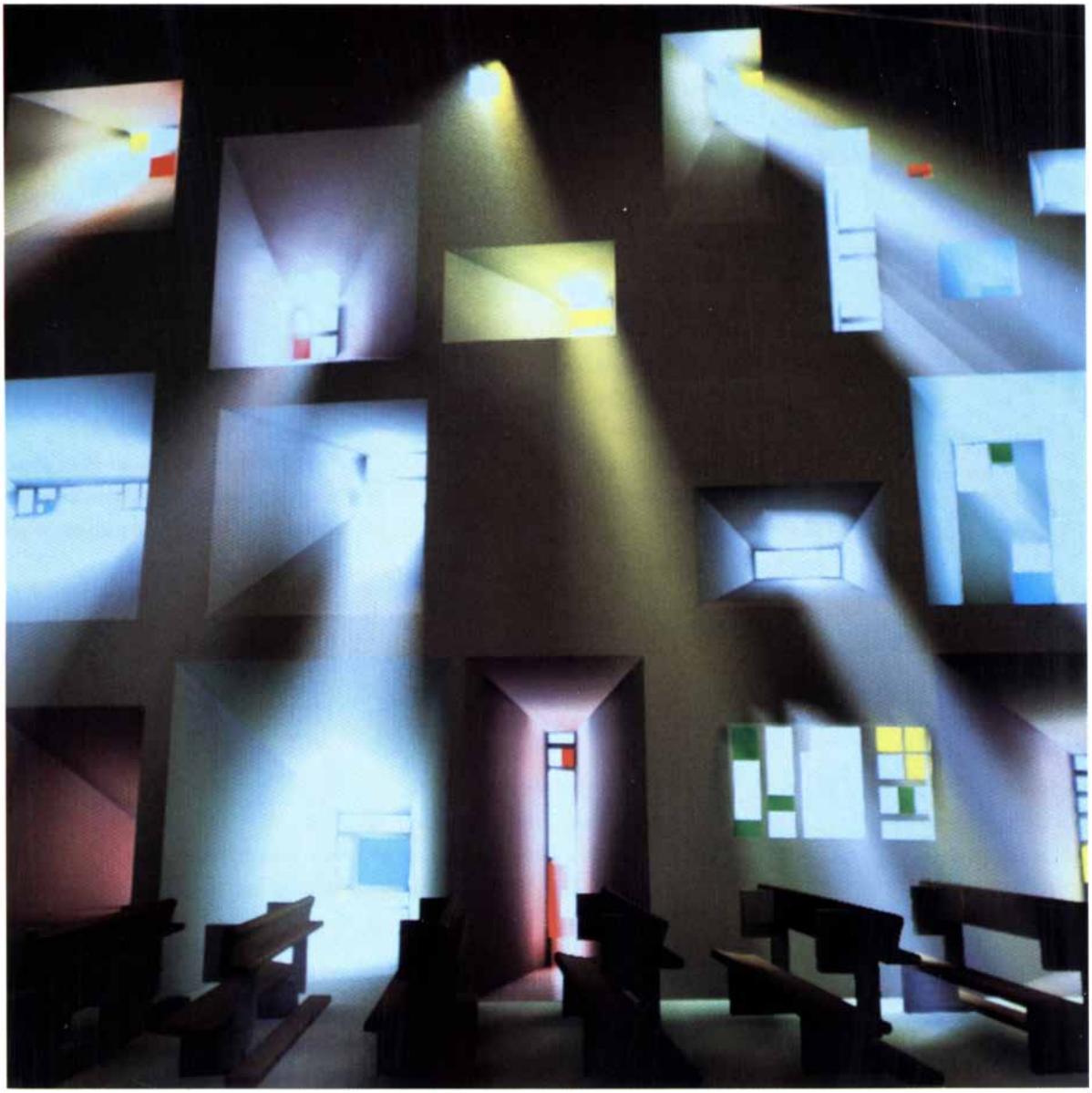
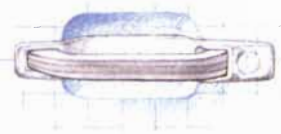
The new epidemic of sexually transmitted diseases.

The quest for the origin of life.

Chaos in the brain may shape perception.

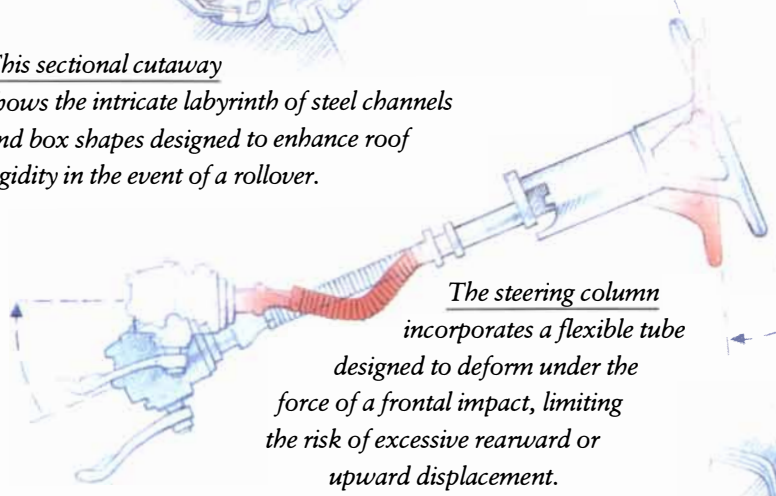


***Vivid computer graphics** replace architects' pencil sketches and handcrafted models with realistic moving images.*

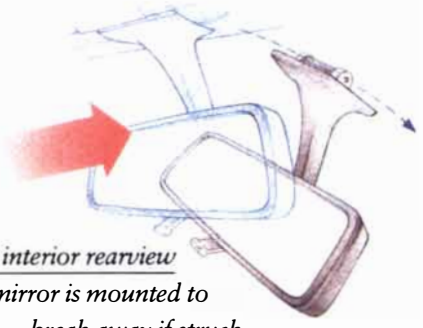


The exterior door handle is not a styled flap but a sturdy grip. Its looped shape is meant to permit maximum pulling force should rescue assistance ever be needed.

This sectional cutaway shows the intricate labyrinth of steel channels and box shapes designed to enhance roof rigidity in the event of a rollover.

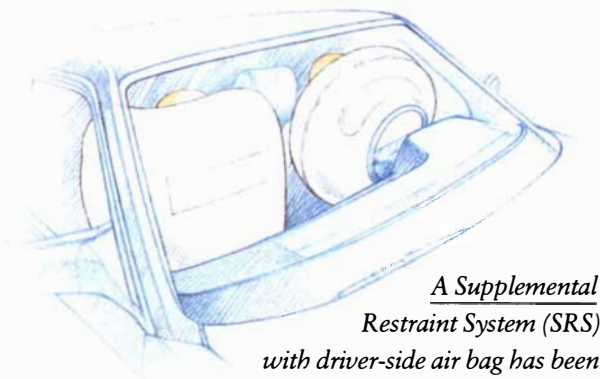


The steering column incorporates a flexible tube designed to deform under the force of a frontal impact, limiting the risk of excessive rearward or upward displacement.



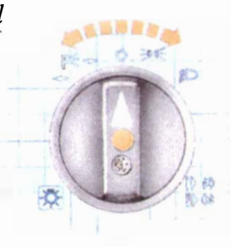
The interior rearview mirror is mounted to break away if struck with moderate force.

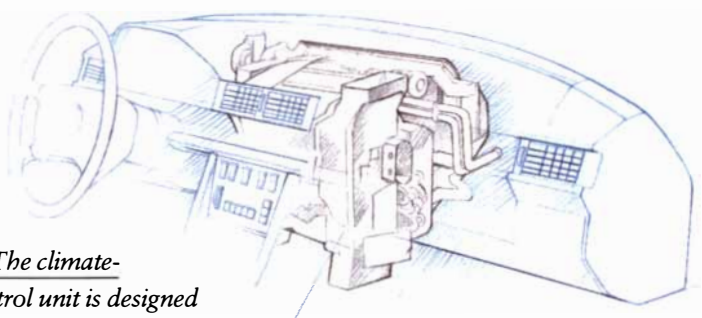
The frontal structure is designed to absorb and channel kinetic energy not only in head-on but also offset frontal impacts—more frequent and more severe. Mercedes-Benz pioneered both the basic energy-absorbing body concept and this offset enhancement.



A Supplemental Restraint System (SRS) with driver-side air bag has been standard in every Mercedes-Benz since 1985. On many models, the system now includes both driver and front passenger air bags.

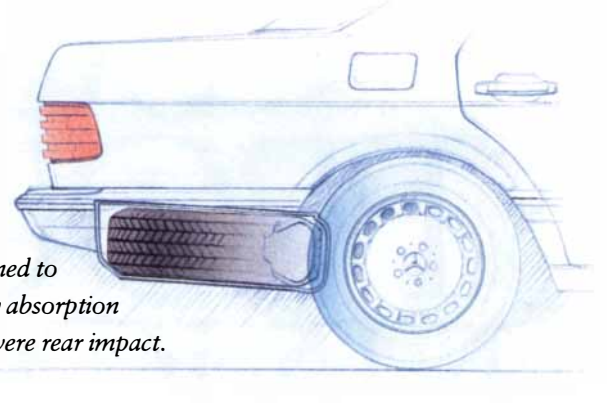
Like every interior control and lever, this recessed headlight-control switch is designed and shaped and placed to help reduce the chance of occupant injury in a severe impact.





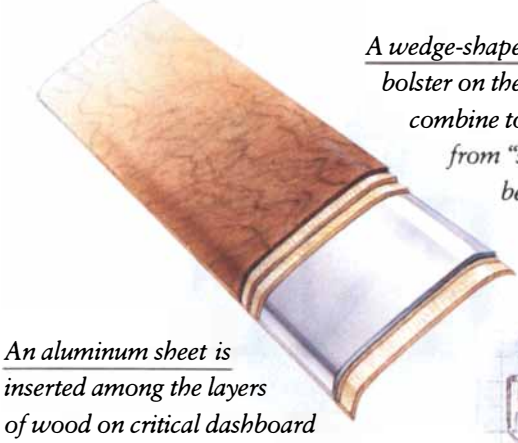
The climate-control unit is designed to be crushable in a severe impact, minimizing the risk of its being pushed rearward into the passenger area.

Forward occupant movement in certain impacts is limited by emergency tensioning retractors, designed to tighten slack in both front seat belts within milliseconds of such an impact.

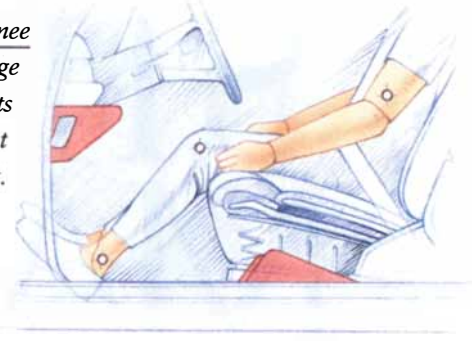


The spare tire's placement is designed to add extra energy absorption in case of a severe rear impact.

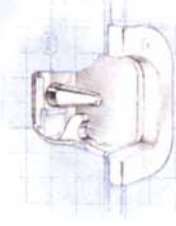
A crash course in Mercedes-Benz



A wedge-shaped seat insert and a padded knee bolster on the instrument panel's lower edge combine to help prevent front occupants from "submarining" under their seat belts in a severe frontal impact.



An aluminum sheet is inserted among the layers of wood on critical dashboard areas to help prevent splintering under the force of a direct impact.



Recognizing the importance of keeping occupants inside the car in a severe impact, Mercedes-Benz places extreme importance on door-lock design. This cone-type lock was patented in 1959 and has since been steadily refined.

The most effective single safety element is still the seat belt. So please, buckle up—even if you drive a Mercedes-Benz. For more information about Mercedes-Benz safety, call 1-800-243-9292 or visit your authorized Mercedes-Benz dealer. Some of the safety features depicted vary from model to model.

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SCIENTIFIC AMERICAN

February 1991 Volume 264 Number 2

Scientific American (ISSN 0036-8733), published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017. Second-class postage paid at New York, N.Y., and at additional mailing offices. Authorized as second-class mail by the Post Office Department, Ottawa, Canada, and for payment of postage in cash. Subscription rates: one year $36, two years $64, three years $88 (outside U.S. and possessions add $11 per year for postage). Subscription inquiries: U.S. only 800-333-1199; other 515-247-7631. Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537.

DEPARTMENTS

We're counting on Brian to produce a Nobel prize winner.

If all the best engineering and science students go directly into industry, who will teach the next generation of American engineers and scientists?

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Rockwell is a $12 billion company with more than 100,000 employees worldwide. Our people have a common goal: Understanding our customers and satisfying them with the innovative application of science and technology. We never stop reaching higher.

THE COVER is a computer-generated rendering of Le Corbusier's chapel at Ronchamps in France. The image was produced from a three-dimensional computer model of the building assembled by Paul Boudreau and Keith Howie in Ithaca, N.Y. New workstation computers can generate slightly simpler versions of such images (without the beams of light) at rates of several frames per second (see "Computers and Architecture," by Donald P. Greenberg, page 104).

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Cover computer rendering by Eric Haines

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LETTERS

Taming Missile Threats

To the Editors:

"Third World Ballistic Missiles," by Janne E. Nolan and Albert D. Wheelon [SCIENTIFIC AMERICAN, August 1990], was heavily descriptive and minimally prescriptive. The authors offer little in the way of practical approaches.

Perhaps we can learn from the superpower experience. Nuclear interdependence has been central to superpower relations since the 1950s, when deterrence and mutually assured destruction locked U.S. and Soviet self-interests together. The notion that the diffusion of strategic weapons could have been prevented is a fallacy: history shows that knowledge has rarely been contained. Disarmament is not a panacea, because the superpowers will most likely continue to base their strategies on mobilization timetables for reconstituting their arsenals.

What has changed fundamentally in the superpower equation is the emergence of a global interdependence that also involves economic, environmental, demographic and health security. Mutual self-interest has begun to outweigh exclusive competitiveness. As interdependent interests expand, the utility of strategic weapons diminishes. The nations of the Third World should similarly be brought into greater nonmilitary interdependence with their competitors so that self-interest will deter the use of strategic weapons.

GEORGE A. GELLERT
Harvard Institute for International Development
Cambridge, Mass.

Fighting Words

To the Editors:

Hooray for Doreen Kimura ["Science and the Citizen," SCIENTIFIC AMERICAN, October 1990]! She hit the nail squarely on the head with her comment about linguists who "come with very strong preconceptions about how things are organized" and "don't find anything out." Her profile contrasts sharply with that of Noam Chomsky ["Science and the Citizen," SCIENTIFIC AMERICAN, May 1990]. The basic tenets of Chomsky's view of language can be traced to Aristotle, and the bulk of its intellectual baggage was built up before the scientific revolution. The fundamental categories of language accepted by Chomskian linguists have failed markedly to relate to observable linguistic phenomena. Yet the strident voices of Chomsky and his followers have drowned out those of the minority of contemporary linguists who are looking at language in a responsible way, often with striking results. Chomsky bears responsibility for trashing what ought to be one of the most fruitful areas of scientific endeavor—the study of human language.

ALAN HUFFMAN
New York City Technical College of the City University of New York

Energy for Earth

To the Editors:

Your special issue "Energy for Planet Earth" [SCIENTIFIC AMERICAN, September 1990] is an excellent compilation and should be required reading for the American public and for our lawmakers and regulators. A discussion of the contributions of geothermal energy, however, seems to have fallen through the cracks. Geothermal energy, the heat of the earth, now generates about 5,700 megawatts of electric power. The development of geothermal power has been highly successful in the industrialized countries, such as the U.S., Japan, Italy and New Zealand. Many developing countries throughout the world also have large geothermal resources. (The Philippines and Mexico are the second and third largest generators of geothermal electricity after the U.S.) Although the world's geothermal resource base is poorly quantified at present, it is clearly very large.

The substitution of geothermal energy for fossil fuels has beneficial environmental effects: geothermal plants emit low levels of greenhouse and acid-rain gases, and they require only a small amount of dedicated land. The plants also have a better on-line record than fossil-fueled or nuclear power sources.

Utilities in Indiana, Florida and Ontario are providing assistance to customers who convert to geothermal heat pumps. Tens of thousands of megawatts of installed electrical generating capacity could be avoided by converting to ground-source heat pumps in the U.S. alone. Unfortunately, the geothermal community has done a poor job of presenting its accomplishments and potential to the public.

PHILLIP MICHAEL WRIGHT
Technical Vice President
University of Utah Research Institute
Salt Lake City

To the Editors:

Hasn't it occurred to any of the authors or editors of your September issue that the only definitive way to save planet Earth is by human population control? Earth's supply of energy is not limitless. Unless human population growth is kept in check, there will not be enough energy to support it.

D. H. MITCHEL
Denver, Colo.

To the Editors:

In "Energy for Motor Vehicles" [SCIENTIFIC AMERICAN, September 1990], Deborah L. Bleviss and Peter Walzer accurately describe the spread of automobiles and the increasing amount of petroleum they consume as threats to energy security and the environment. Yet the authors dismissed the alternative to automobiles, public transportation. Modern public transportation systems were used nine billion times in 1989 by passengers who did not see them as "inaccessible, uncomfortable and dangerous."

Improving the fuel efficiency of automobiles is indeed a high priority, but neglecting the more efficient and environmentally sound alternative of public transportation is wasting an opportunity to save energy and help clean the air right now.

JACK R. GILSTRAP
Executive Vice President
American Public Transit Association
Washington, D.C.

ERRATA

In "A Roman Factory," by A. Trevor Hodge [SCIENTIFIC AMERICAN, November 1990], the productivity rate for one millstone in the Barbégal mill should have been listed as 24 kilograms of flour per hour.

In "Global Warming Trends," by Philip D. Jones and Tom M. L. Wigley [SCIENTIFIC AMERICAN, August 1990], the caption of the figure on pages 86 and 87 should have said that the air above the ocean surface was cooler, not warmer. On page 90, the text and figure caption should have said that the El Niño phenomenon leads to a temporary rise in global mean temperatures, not a fall.

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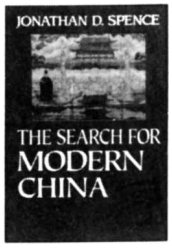

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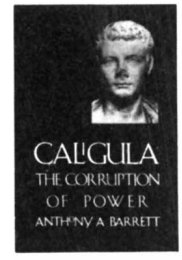

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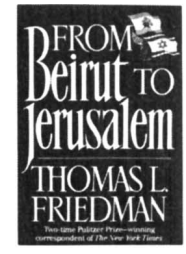

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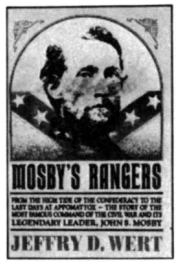

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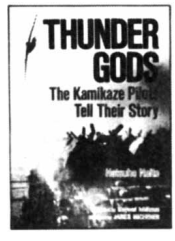

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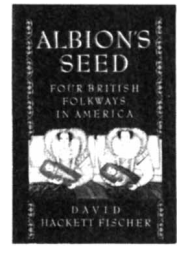

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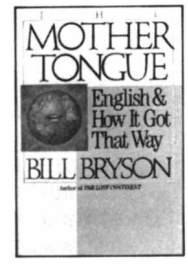

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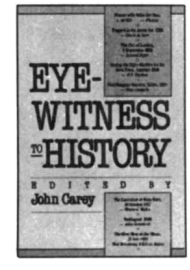

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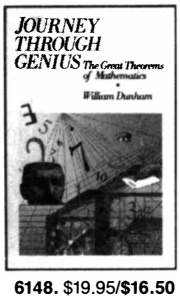

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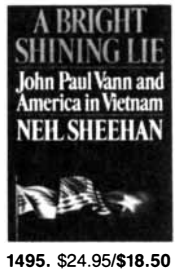

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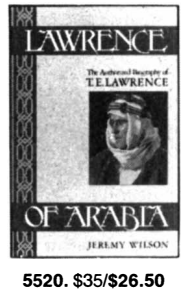

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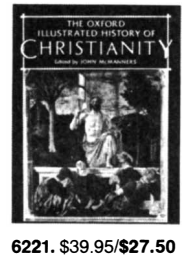

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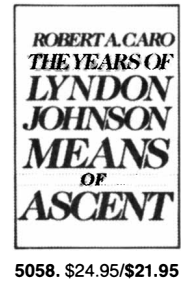

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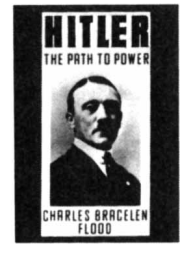

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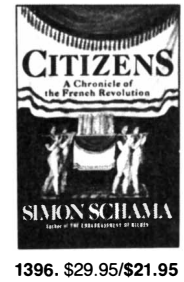

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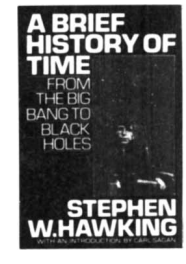

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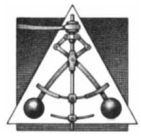
50 AND 100 YEARS AGO



FEBRUARY 1941: "Since the first of 1941, broadcasting stations of a new type have been operating on commercial schedules in various parts of the country. Their signals can be heard only with special receivers. These stations employ the frequency modulation (FM) system first described in these pages in the May 1939 issue. Boiling the whole thing down to the essence, we find that FM broadcasting, as compared with conventional or amplitude modulation (AM) broadcasting, differs in three important respects. First, and possibly most important, is a broadened range of tonal reproduction. Second is an almost total freedom from both natural and man-made static. Third is the lack of interference between transmitters operating in the same channel. The last point is not only important to the listener, who will not be troubled by heterodyne whistles when using an FM receiver, but has far-reaching economic consequences."

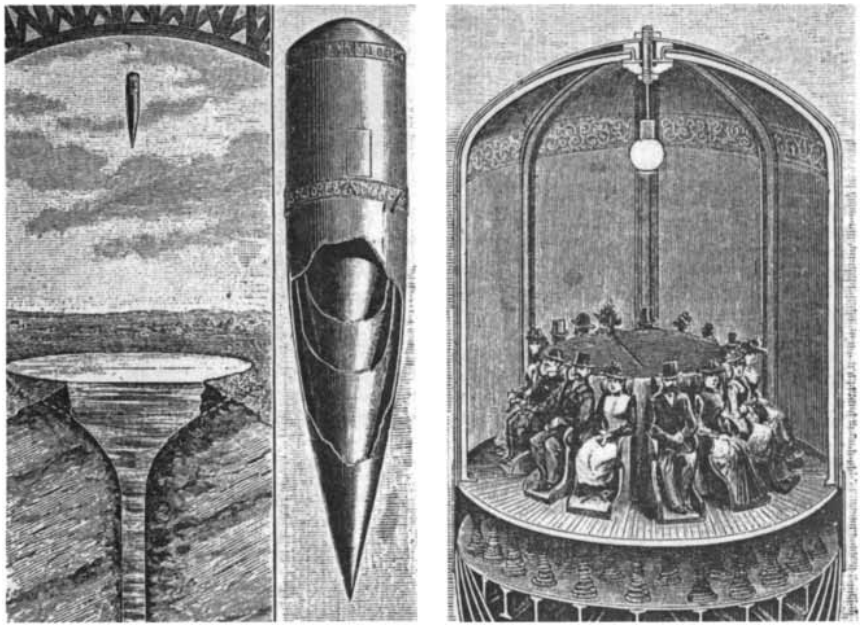
"For years Uncle Sam has been turning away color-blind flyers who wanted to go through the Army Air School at Randolph Field; now he is looking for them, according to *Ethyl News*. It has recently been discovered that camouflage, so successful in hiding guns and barracks from enemy aircraft, doesn't fool a color-blind man the least bit. He can see right through it. The discovery was made by accident at Fort Sill, Oklahoma, when the Army was testing the effectiveness of camouflaging heavy guns so they could not be spotted from the air."

"Out in East Springfield, Ohio, there is a new listening laboratory in which the sound of your own breathing resembles that of a small air bellows, and the snap of your fingers sounds like a pistol shot. This new laboratory of the Westinghouse company is used as a sound inspection laboratory for household refrigerator units. It is the only sound-proof chamber in the world which is not completely sealed from the outside when in operation. In construction it resembles a labyrinth, or maze; it consists of a series of winding passages with 90-degree and 180-degree turns. Near the middle of these heavily padded passageways is the actual sound-proof chamber, a 21,000-pound 'floating room,' which is supported in the air by 20 steel springs. The winding passageways act as baffles to destroy reflected sound waves."

FEBRUARY 1891: "Professor Hertz's experiments on electrical undulations are now declared to have demonstrated: (1) that the medium which intervenes in the phenomena of electrical action is the same as that which is the seat of luminous phenomena; (2) that both species of perturbations are propagated under the same conditions, and with equal velocity; (3) that there is an identity of nature between certain electrical and luminous phenomena. Moreover, he has realized an arrangement whereby the length of the electrical waves is diminished; thus approaching the character of the luminous wave, and shadowing forth the prospect of the direct industrial production of electric light. The electric arc lamp wastes nine-tenths of its energy in non-luminous, invisible heat rays. If these rays could only be quickened, they would appear as light; and Professor Hertz is in hopes of being able to do something toward this end by manipulating alternating currents."

"In the railway stations and ferry houses may be found machines which, for a penny, will dole out a drop or two of liquid which passes for perfumery, and which, in many cases, serves as a thin mask for bodily uncleanliness. This very clever device was patented by Mr. Lewis C. Noble, of Boston, Mass., on November 19, 1889. But in turning back the pages of history we find that in ancient Egypt, the priests made the distribution of holy water a source of revenue by means of a lustral water vase substantially like a modern vending machine. The mechanism, described by Heron more than two thousand years ago, simply serves as another proof of the saying 'There is nothing new under the sun.'"

"If a rapid vertical fall assumes an exceptional character of magnitude, it will produce physiological disturbances of the same kind as those that a person experiences in rustic swings, toboggan slides, merry-go-rounds, the sight of abysses, etc. Such is the field to be exploited. A tower several hundred meters in height and a closed cage constitute the plant. The passengers enter the cage, which is allowed to drop freely from the top of the tower. At the end of 100 meters fall the velocity acquired is 45 meters per second, and at the end of 300 meters it is 77 meters. In order to render this maneuver practical, it suffices to receive the passengers safe and sound at the end of the trip. This object may be realized by giving the car the form of a shell with a very long tapering point, and by receiving it in a well of water of sufficient depth. The accompanying figures give the general aspect of such a shell."



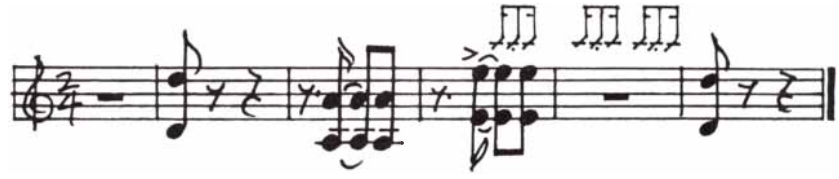
Free fall as a form of amusement

MAN: Last week my girlfriend broke up with me. Then she traded in her Toyota Corolla for this Eagle Summit.

OFF-CAMERA VOICE: Well, did she give you a reason?

MAN: She said she needed her space.

(MUSIC)



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SCIENCE AND THE CITIZEN

Iraq's Nuclear Threat

Is the U.S. underestimating Hussein's nuclear capability?

Ask the Bush administration, members of the Senate Armed Services Committee and intelligence officials when President Saddam Hussein will possess a nuclear weapon, and they all seem to agree that he will not get one for at least a year. But nuclear-weapon experts caution that intelligence information known to the public is incomplete. And, they warn, Baghdad could already be much further along. "It is not impossible that Iraq has several nuclear weapons now," says Theodore B. Taylor, a leading authority on the design of nuclear weapons.

Few experts doubt that Iraq has at least enough nuclear material to form the core of some type of nuclear device. Iraq salvaged 12 kilograms of 93 percent pure uranium 235 after an Israeli air attack destroyed a French-designed research reactor in 1981, and it also holds several kilograms of uranium 235 in a Soviet-supplied reactor.

Potent protector, the last flight of Astro, supertransistors, nuclear risks

As a signatory of the Nuclear Non-Proliferation Treaty, Iraq allows the International Atomic Energy Agency (IAEA) to inspect its nuclear facilities, including the materials from the two reactors. In November, IAEA used what technical experts regard as foolproof methods to verify that the nuclear materials under its supervision had not been diverted for use in a weapon.

But IAEA safeguards are not a source of comfort to many insiders, because Iraq could fashion its materials into a nuclear weapon within a matter of weeks if it has a detonator and the machining equipment necessary to shape highly enriched uranium. U.S. government sources have not revealed in any detail whether Iraq has such capabilities.

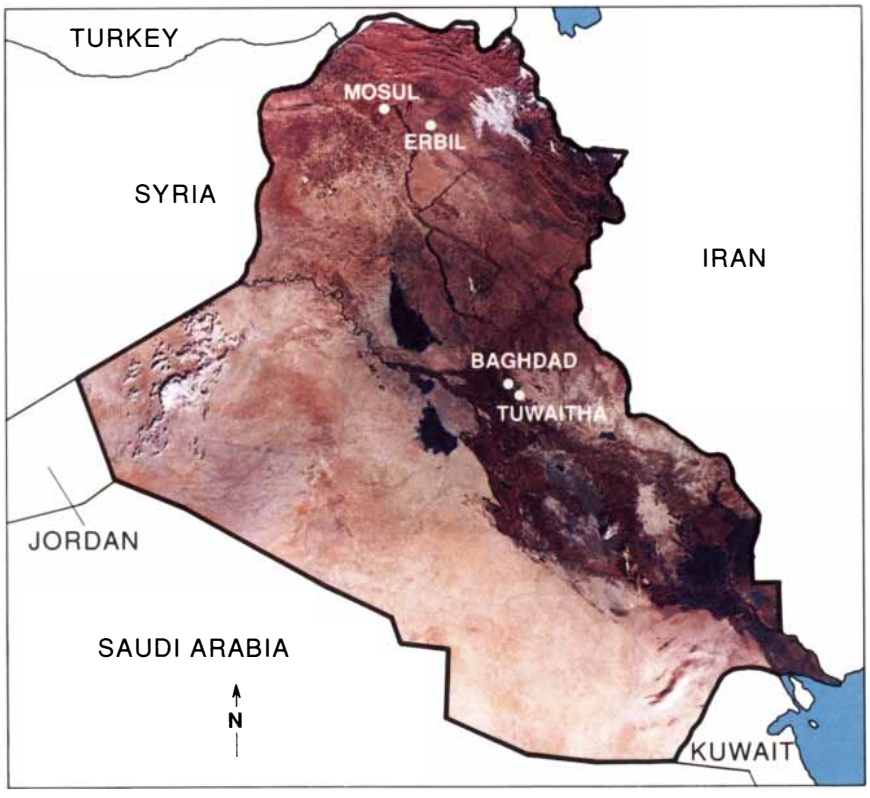
Iraq does appear to be intent on designing its own nuclear devices. According to published reports, Al Qaqaa Military Research and Development Institute is creating the chemical explosives required for a nuclear detonator. Furthermore, three employees of the institute have attempted to import krytrons, capacitors used to trigger nuclear weapons. They were caught on March 29, 1990, in a sting operation conducted by the U.S. Customs Service Officials.

Experts conclude from these events that Iraq plans to build an implosion weapon similar in design to the bomb the U.S. dropped on Nagaski during World War II. In this type of weapon, chemical explosives surround a core of nuclear material. Krytrons help to deliver a precisely timed signal to detonate the explosives, so that the nuclear material is compressed rapidly and uniformly. The compression initiates a fission reaction that powers the nuclear explosion.

Iraq could develop a nuclear weapon without testing it, explains Richard L. Garwin, an expert in nuclear affairs at the IBM Thomas J. Watson Research Center. "The question," he comments, "is whether that country would have confidence that it would work or even whether the design might be such that it would never work."

Whether or not Iraq can build such a nuclear detonator cannot be determined, Taylor says, given the amount of information publicly known. Baghdad's nuclear capability, he adds, "depends entirely on the skills, the facilities, the intentions and the knowledge of the people doing the design and the fabrication." A conventional implosion bomb made from 25 kilograms of 90 percent pure uranium can yield more than 15 kilotons, about the explosive power of the Hiroshima bomb. Assuming Iraq has only 12.5 kilograms of weapon-grade material, it would have to build a sophisticated implosion bomb, including advanced detonators and reflectors that facilitate the nuclear chain reaction.

Such technicalities may be pointless if Iraq has clandestinely obtained weapon-grade nuclear materials. In 1982 it tried to do just that: military officials attempted to arrange a deal with Italian arms smugglers who claimed to have



IRAQ'S NUCLEAR FACILITIES are reportedly near Mosul, Tuwaitha and Erbil.

SCIENCE/SCOPE®

Inexpensive aluminum clips help trim nearly $200,000 from the cost of a satellite. The clips were designed and used by Hughes Aircraft Company to hold major structural elements of the new HS 601 communications satellites together. Previously the satellites were bonded together, a time-consuming process because of the close tolerances involved and the approximately one week required for each bond to cure. With about 250 structural joints per satellite, the clips save nearly $200,000 in hands-on labor per spacecraft. Another benefit of the technique is the elimination of bond testing. Verifying the torque, a much faster process, is all that's required with the new process.

The U.S. Navy now has the first full-function simulator for military hovercraft. This amphibious vehicle, called the Landing Craft Air Cushion (LCAC), incorporates state-of-the-art hovercraft technology. It is one of many training systems built by Hughes Simulation Systems, Inc., a subsidiary of Hughes Aircraft Company. The Full Mission Trainer accurately replicates the amphibious environment and dynamic responses of the craft, while providing an effective training platform for all crew positions. LCAC simulates many unprecedented operations at sea. It creates real-time, multiple sea-state, three-dimensional wave and ocean models, and integrates visual and motion experience.

Gunners in U.S. Army M1 Abrams tanks are able to see and pinpoint targets day or night using laser rangefinder and thermal imaging systems produced by Hughes. These systems are also being applied to advanced fire control and air defense systems employed by other Free World Countries. Deliveries of the systems have passed the 8,000 mark, and over the 10-year life of the program, unit prices have decreased nearly 50 percent as the result of significant increases in production efficiency.

More than 20 nations protect their sovereign airspace with command, control and communications systems produced by Hughes, the world's most experienced developer of automated air defense systems. The systems are comprised of air defense radars, computers, displays, communications and other electronic subsystems. Target information is transmitted through data links to data processing centers, where computers automatically track and report the aircraft's speed, altitude, and course. The systems are tailored to the requirements of each country based on geography, military equipment, and size and structure of military forces. Nations equipped with Hughes systems include Japan, Switzerland, the U.S., Spain, Canada, Malaysia and European NATO members Belgium, Denmark, Greece, Italy, the Netherlands, Norway, Turkey, the United Kingdom, and West Germany.

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33 kilograms of plutonium. When the smugglers could not produce samples of the plutonium, the deal fell through. Italian government sources later reported that they found no evidence that the smugglers had plutonium.

Yet Baghdad may also be able to produce its own weapon-grade material without diverting material from reactors. According to a report commissioned by the Simon Wiesenthal Center, companies in France, Switzerland and Germany have provided Iraq with technologies essential for constructing gas centrifuges that concentrate uranium 235 in the form of uranium hexafluoride gas. When this corrosive gas is transferred through a series of 1,000 centrifuges, it is enriched from 71 percent to about 90 percent purity. In a year such a system can produce several kilograms of uranium 235, official sources say.

Notably, on July 15, 1990, German authorities seized a shipment of Swiss-made machinery that was built of the corrosion-resistant steel necessary for gas centrifuges. According to Michael Eisenstadt of the Washington Institute for Near East Policy, Brazil, Niger and Portugal have provided Iraq with hundreds of tons of uranium ore concentrate, which can be converted into uranium hexafluoride in a series of complicated chemical steps. Polish engineers who were recently held as hostages by Iraq claim that the gas conversion process is being developed at the Al Qaim chemical plant.

To estimate how long it might take Iraq to build a uranium-enrichment plant, experts point to similar efforts by Pakistan. Workers there labored for 10 years to develop and construct a few thousand centrifuges that had the capability to produce enough material for a bomb. Because Iraq has already demonstrated more technical prowess in weapon technology than Pakistan—an unconfirmed report says it currently has a cascade of centrifuges—U.S. intelligence experts estimate that Baghdad could be producing weapon-grade uranium within five years.

The Bush administration has seemed doubtful about the effectiveness of the embargo, a feeling that sharpens into frank concern with respect to nuclear technologies. Independent experts agree. "The embargo will be useful but not airtight," admits Leonard S. Spector of the Carnegie Endowment for International Peace. "It will still be possible for Saddam Hussein to obtain bit by bit the hardware he needs for the infrastructure for the bomb."

Spector, who has studied nuclear proliferation for more than 10 years, recommends that the IAEA exercise its untested power to inspect any site where it suspects nuclear research is being conducted. If IAEA was denied access to the site or found that the facility was producing material for nuclear weapons, Spector says, it should have the power to impose sanctions or take other action.

Defusing Iraq's bomb program by attacking key nuclear facilities reported to be near Mosul, Tuwaitha and Erbil does not promise to be easy. At the very least, experts say, Iraq should be able to hide nuclear weapons or their components once they have been assembled. "The chances of destroying whatever they have," Taylor comments, "are extremely small." —*Russell Ruthen*

The A Team

Vitamin A and its cousins are potent regulators of cells

The ancient Egyptians knew there is strong medicine in livers. They used juices squeezed from them to treat night blindness and other eye disorders. Today the active principle that aided Egyptian eyesight is known as retinol, or vitamin A. But that fat-soluble chemical does far more than give rise to the light-sensitive pigment that allows vision. Many investigators now regard vitamin A and its kin as part of a small number of master control systems that orchestrate cell form and function and play a key role in protecting against cancer.

"Vitamin A has moved to center-stage position in biology," says George Wolf, a nutrition researcher at the University of California at Berkeley. Indeed, one of its products, retinoic acid, acts as a hormone that plays a pivotal role in cell differentiation in embryos. A genetic error that affects its action has recently been implicated in a form of leukemia. Meanwhile other chemical variants of vitamin A, known as retinoids, are powerful—and dangerous—drugs: one protects against some cancers but also causes birth defects.

Because the body cannot make vitamin A from scratch, it must obtain the chemical from food either directly or by splitting in half compounds such as beta carotene, the orange pigment that gives carrots their color. In industrialized countries, vitamin A deficiency is almost unheard of, but according to one estimate, 500,000 children go blind in poor countries each year for lack of it. Many also die. Vitamin A deficiency stunts growth and increases susceptibility to infection. Laxmi Rahmathullah of the Aravind Children's Hospital in Madurai, India, and his colleagues recently found that weekly vitamin A supplements cut deaths from disease among preschool children by more than half.

The vitamin's protective power works through its effects on the cells that line the skin, the cornea, the lungs and the digestive tract. Skin abnormalities, some resembling cancerous changes, were among the first of the many effects of vitamin A deficiency to be noticed in humans. Researchers early this century also found that a severe lack of the vitamin causes stomach cancer in rats.

Intrigued by such observations, investigators have experimented with synthetic retinoids. One, all-*trans* retinoic acid, known commercially as tretinoin or Retin-A, is used to treat severe acne. Publicity in recent years has also led to its being widely used to make wrinkled skin look younger (although it has not been proved safe and effective for that purpose, according to the National Institutes of Health).

Other retinoids, as well as beta carotene, have been found to suppress malignant changes in cells grown in culture and in experimental animals. Richard C. Moon of the Illinois Institute of Technology has shown that a synthetic retinoid called 4-HPR suppresses mammary cancers in rats. It is now being tested in breast cancer patients.

Epidemiological clues provided further evidence of a link between retinoids and cancer. Many investigators have confirmed that people who acquire the disease are likely to have low blood levels of retinol and to consume less beta carotene than average. These observations spurred efforts in the 1980s to see whether cancer incidence could be chemically inhibited.

People in developed countries already consume more vitamin A than they need, so efforts have focused on beta carotene. Beta carotene causes nothing more unpleasant than a yellowing of the skin if taken in excess. Vitamin A, in contrast, is poisonous (eating polar bear livers, an especially rich source, can be fatal). And quite apart from its chemical kinship with vitamin A, beta carotene is becoming recognized as a potentially beneficial quencher of dangerous oxidizing chemical fragments, such as singlet oxygen, which are thought to cause cell damage.

The antioxidant effect of beta caro-

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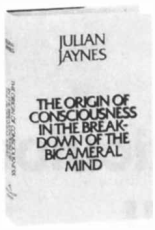

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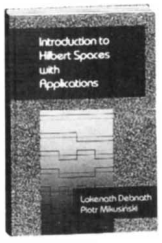

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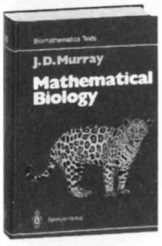

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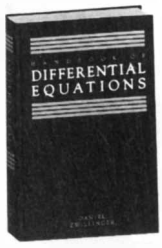

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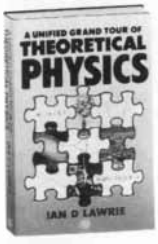

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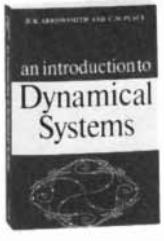

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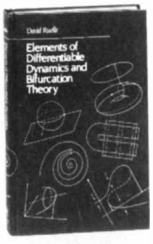

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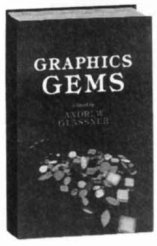

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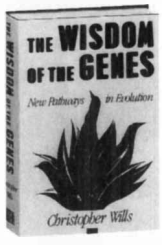

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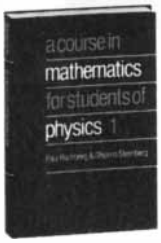

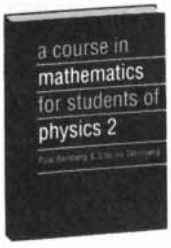

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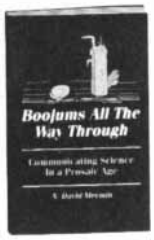

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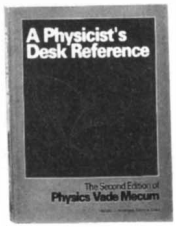

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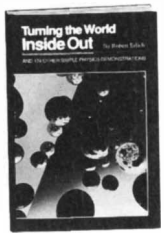

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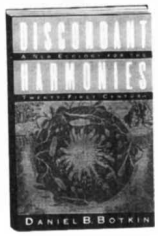

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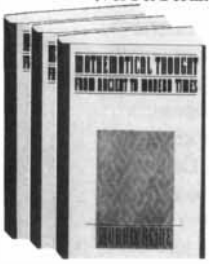

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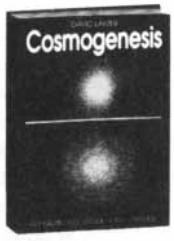

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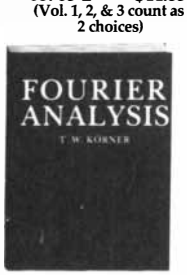

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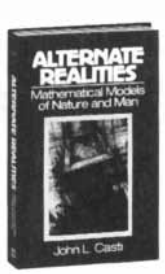

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tene was recently highlighted in preliminary results from a study designed to investigate the effects of aspirin on heart disease. According to Charles H. Hennekens of Harvard Medical School, a subgroup of the participants who took beta carotene had a lower combined incidence of heart attacks and strokes, possibly because beta carotene inhibited oxidation of cholesterol deposits. One theory holds that oxidized products of cholesterol are more harmful than the chemical itself.

Results from a five-year study on possible anticancer activity of beta carotene, reported recently by a team headed by E. Robert Greenberg of Dartmouth Medical School, were disappointing, however. They failed to show any protective effect on skin cancer in patients who had previously had the disease. Nevertheless, Hennekens and others believe that beta carotene might be shown to prevent other cancers in longer trials still in progress.

More encouraging results emerged recently from a clinical trial using the synthetic retinoid isotretinoin, which is marketed as an acne remedy under the tradename "Accutane." The study was conducted by Waun Ki Hong, an oncologist at the University of Texas M. D. Anderson Cancer Center in Houston, and his colleagues. Hong's group found that isotretinoin prevented new head and neck cancers in patients who had already had them once. "We think that through regulation of specific genes for growth and differentiation, retinoids can restore normal growth and differentiation even in premalignant cells," Hong says.

Isotretinoin has a dark side, too. It may have caused birth defects in approximately 90 babies in the U.S. alone, by one count. This tragic side effect arises probably because it interferes with natural development mechanisms that rely on retinoids. Doctors now warn that women taking the drug should not conceive.

Gregor Eichele, now at Baylor College of Medicine in Houston, and Christina Thaller have elucidated one such mechanism in experiments conducted on developing chicken wings. The researchers showed that a concentration gradient of retinoic acid arises across the embryonic wing bud, which influences the developmental pathway cells take. Altering the retinoic acid concentration causes the wings to develop extra digits. That indicates retinoic acid is a "morphogen" that guides normal development. "Retinoic acid imprints a program," Eichele explains. "It is an instructional molecule."

Four years ago Pierre Chambon of the Louis Pasteur University in Strasbourg and Ronald M. Evans of the Salk Institute for Biological Studies independently made a discovery that goes a long way toward explaining how retinoids achieve their potent effects. The molecular biologists found that cell nuclei contain receptors—binding proteins—that affect gene activity when they bind to retinoic acid (and probably other retinoids).

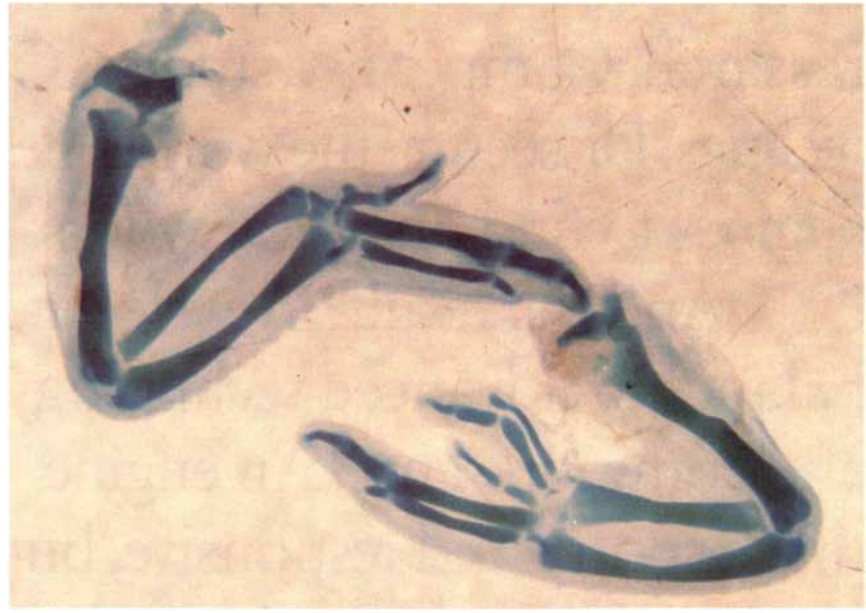
Since then, a variety of such receptors have been found, although their exact functions remain obscure. "We know different receptors are affected differently by various retinoids," Chambon says. Some regulate their own rate of production, whereas others have complex interactions with other receptor systems in the cell nucleus, such as thyroid hormone receptors.

To Eichele, the presence of such receptors suggests that retinoids may be part of a signaling system that controls gene activity. Among the genes whose activity is known to be affected by the binding of retinoic acid is the gene for laminin, a protein in the matrix that holds cells in place. Retinoic acid could affect communication between cells, Eichele speculates. There are also receptors for retinoic acid outside the nucleus, whose function is unknown.

Recently Antonio Simeone of the International Institute of Genetics and Biophysics in Naples and his colleagues showed that increasing the concentration of retinoic acid activates successive members of one type of so-called homeobox gene. That could be an important clue to the action of retinoic acid, Chambon says. Homeobox genes are known to play a key role in specifying developmental pathways, certainly in invertebrates and probably in mammals as well.

Retinoic acid's role in development may explain its ability to make cancer cells revert to stable cell types, Eichele believes. A group of researchers headed by Hugues de Thé at the Pasteur Institute in Paris recently reported the probable direct involvement of a nuclear retinoic acid receptor in acute promyelocytic leukemia. They discovered that in cancer cells the gene for one retinoic acid receptor is often displaced and fused with a previously unknown gene, where it probably produces an abnormal product. The abnormal product, de Thé suggests, might block genes normally regulated by retinoic acid and so cause a breakdown in control.

"Since retinoic acid is involved in differentiation and development, it is not too surprising that it has an effect on tumors," Chambon remarks. "Whether it promotes or interferes with other regulatory factors we don't know." Investigators in many laboratories are putting in long hours probing this versatile and potent chemical and its relatives. *—Tim Beardsley*



***ROLE OF RETINOIC ACID** in development is shown by these embryo chicken wings. Normal wing* **(left)** *has three digits. A wing treated with retinoic acid obtained from chick embryos* **(right)** *has grown extra copies of two digits. Photo: Gregor Eichele.*

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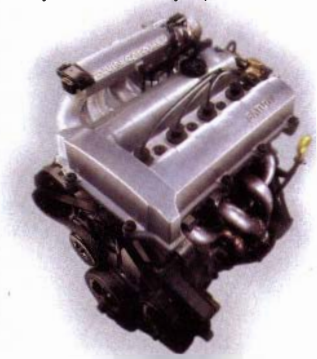

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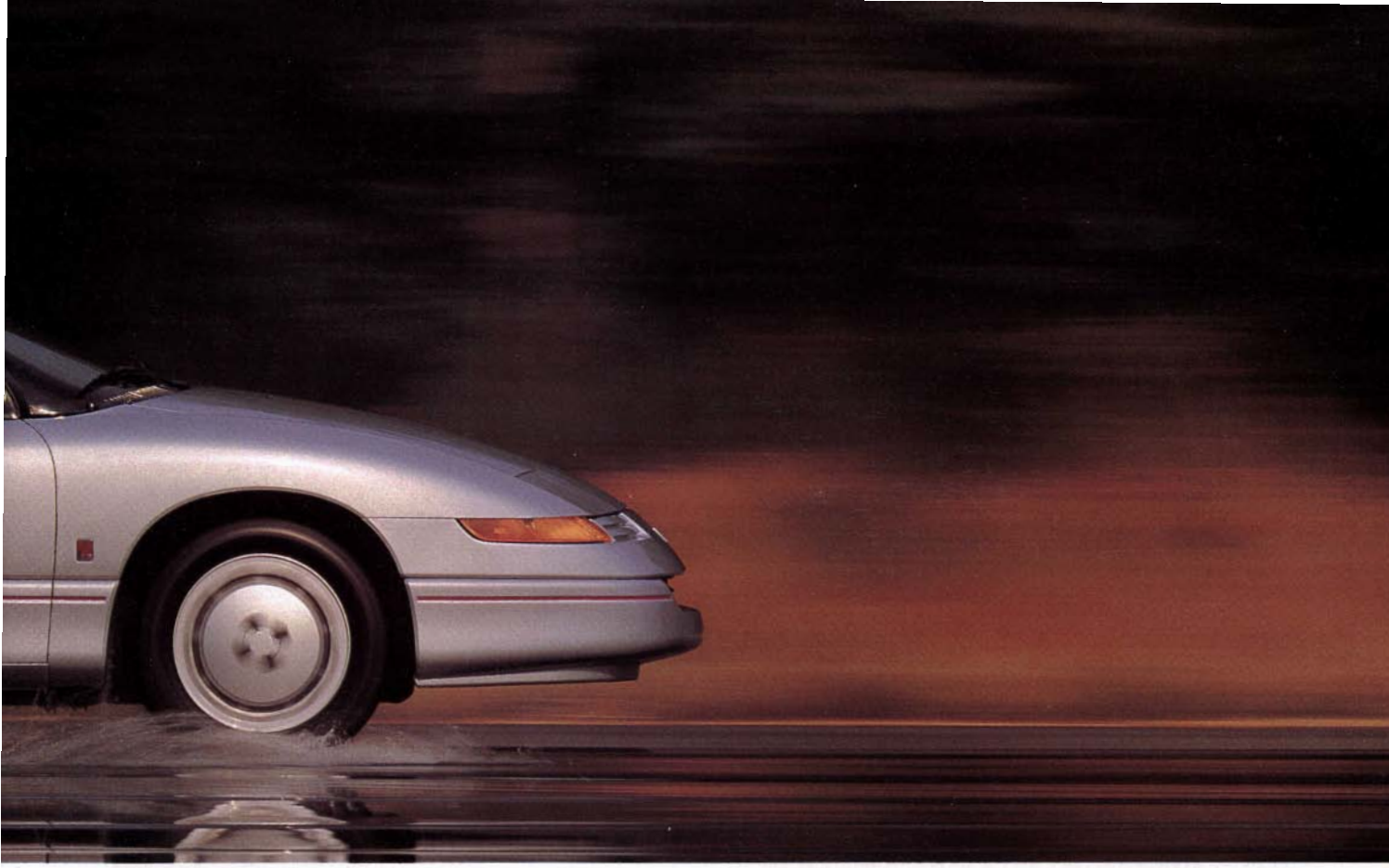

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Drug test results may point to racial discrimination

More than half of all midsize and large companies in the U.S. now test the urine of job applicants for illegal drugs and reject those who come up positive. Advocates of this practice argue that it makes economic sense. They claim that people who test positive for drugs are up to 15 times more likely than nonusers to have accidents or injuries, to miss work and to be fired. Until recently, however, no peer-reviewed report has presented any evidence for these assertions.

Now two such reports, both involving U.S. Postal Service workers, have been published. The studies—one of 2,537 hirees in Boston and the other of 4,396 in other cities around the country—were initiated by the Postal Service four years ago to gather evidence justifying a nationwide drug-testing plan. For two years, the service tested job applicants for drugs. The tests did not affect the workers' applications or subsequent job status. Results were known only to the researchers. Although the reported shortfall in performance among those testing positive was not nearly as severe as had been claimed previously, it was still significant. Not surprisingly, testing proponents have declared that the studies prove the value of testing.

Yet even these relatively modest findings may be unfounded, according to other experts on drug testing. John P. Morgan, a pharmacologist at the City University of New York Medical School, points out that the studies contradict each other on two key measures—accidents and injuries—and that the findings on which the studies concur may be distorted by factors having nothing to do with drug use, such as race.

Indeed, the real surprise in the studies lies in the Boston study, which indicates a possible pattern of racial discrimination. Craig Zwerling, a physician for the Postal Service who headed the Boston study, acknowledges that he and his colleagues were so disturbed by this finding, which he says reveals "a possibility of racially biased firing," that they called it to the attention of the Postal Service management.

Blacks, who accounted for about 6 percent of the Boston workers, were twice as likely as whites to test positive for drugs. But data in Zwerling's study, which was published in the *Journal of the American Medical Association* last November, indicate that blacks overall were absent 33 percent less than whites; blacks had about the same number of accidents as whites but 31 percent fewer injuries.

By these measures, blacks performed better than whites on the job. Nevertheless, blacks in Boston were 44 percent more likely to be "disciplined" and 143 percent more likely to be fired than were whites. Zwerling, who recently moved to the University of Iowa, acknowledges that the datum on the firing of blacks was the single most statistically significant finding in his entire study. Yet he insists that the statistic, which he decided did not merit discussion in his published report, does not negate his conclusions on drug use. He asserts that he adjusted his figures to eliminate distortion from racial factors and that the correlation between drug use and poor performance was still significant.

That assertion is disputed by David C. Parish, a physician at the Mercer University School of Medicine in Georgia who has studied drug testing. He says the Zwerling group used a faulty method for controlling for race and other potentially confounding factors, such as age, sex and job category. A proper analysis, Parish says, may have found a much smaller correlation between drug use and job performance.

The national study, which was published in the *Journal of Applied Psychology* in December, did not even attempt to control for race or other confounding factors, although blacks accounted for 33 percent of the workers. "We weren't interested in that," says Jacques L. Normand, the Postal Service psychologist who led the study. But as in the Boston study, blacks in the national group tested positive for drugs twice as often as whites did.

Theodore H. Rosen, a psychologist and consultant on drug testing, says that bias or other "cultural" factors related to race could have contributed to the firing of positives in the national group—and even to absenteeism. Past studies have shown that Postal Service managers exercise a great deal of discretion in reporting the absenteeism of subordinates, he says.

Overall, both studies found similar patterns of drug use, absenteeism and firings. The national group tested positive at a somewhat lower rate than the Boston group—9 percent as compared with 12 percent. In each study, about two thirds of the positives were triggered solely by marijuana, which persists in the blood for up to four weeks. About one sixth of the positives were for cocaine only. The rest were for nontherapeutic drugs such as opioids, amphetamines and barbituates or for multiple drugs, including cocaine and marijuana.

The Zwerling group reported that marijuana positives were 56 percent more likely than negatives to be absent; cocaine positives were 137 percent more likely and positives for "other drugs" 45 percent more likely. Although the study found no significant increase in the risk of being fired among those testing positive for cocaine, persons testing positive for marijuana were about 100 percent more likely to be fired than nonusers, and those positive for other drugs were 67 percent more likely to be fired than nonusers. Normand, who did not categorize persons who tested positive according to drug, concluded that they were 59 percent more likely to be absent and were 47 percent more likely to be fired.

Only the Zwerling group found any correlation between drug use and accidents and injuries. It reported that Boston workers testing positive for marijuana had 55 percent more accidents and 85 percent more injuries than negatives. The rates for cocaine were similar. Those who tested positive for other drugs, however, did not have elevated accident and injury rates.

Rosen argues that all these accident and injury estimates could be erroneous because the investigators used a suspect method for calculating the risk. The estimates, he notes, were based on the average amount of time that passed before the first incident occurred. According to this method, Rosen explains, someone who has an accident or injury after one month and never thereafter is judged to be roughly twice as accident prone as someone who first has an accident after two months and has several accidents thereafter.

This technique has even been criticized by Normand. "To me, if you have an accident sooner rather than later, that's meaningless," he says. Normand's study found no association between a positive drug test and either injuries or accidents.

Lynn E. Zimmer, a sociologist at Queens College in New York who is writing a book on drug testing, says she has been trying in vain to obtain the raw Postal Service data to see what her own analysis turns up. "It's not out of the question that there will be a difference between positives and negatives" even when the data are properly analyzed, she says. "But these studies certainly don't establish that."

For the Postal Service, the issue is moot. In 1989 it began testing all applicants for drugs and rejecting any who test positive. —*John Horgan*

Disposable Astronomy

No second chance for NASA's Astro

Once again the National Aeronautics and Space Administration found itself staring into the proverbial half-empty glass, and once again astronomers had to content themselves with the notion that at least the glass was half full. This time the source of mixed feelings was Astro-1, a suite of four telescopes that temporarily transformed the cargo bay of the space shuttle *Columbia* into a sophisticated astrophysical observatory.

But a shortened shuttle flight and persistent technical problems hampered the mission, although Astro still managed to observe more than one half of its 250 intended targets. More troubling is the prospect that NASA will mothball the $150-million Astro after only one mission.

Teething problems such as the glitch in Astro's instrument-pointing systems and the failure of a computer control terminal on the shuttle were not unexpected. Astro was conceived as a reusable astronomy platform whose design would be fine-tuned over as many as six flights. Arthur F. Davidsen of Johns Hopkins University, who helped develop one of the telescopes on Astro, muses that "the next mission would go smooth as silk now." But he laughs as he says it: limited funds and a cramped launch schedule mean that Astro probably will never fly again.

Astronomers are especially disappointed because the data Astro did return look so promising. Astro consists of four instruments that are sensitive to ultraviolet and X rays, energetic forms of electromagnetic radiation that are emitted by very hot or violently disturbed celestial objects.

One of these, the *Broad Band X-ray Telescope* (*BBXRT*), was unaffected by the shuttle's computer problems. Exciting measurements have already emerged from preliminary data analysis, reports Peter J. Serlemitsos of NASA's Goddard Space Flight Center, the principal investigator for *BBXRT*. Observations of hot gas in a giant elliptical galaxy imply that the object contains roughly six times as much matter as can be accounted for by its visible emissions. This corroborates other indications that the universe is dominated by "dark matter," which does not reside in stars or bright gas clouds.

Astro's measurements of the X-ray spectra of active galactic nuclei—thought to be the little siblings of quasars—seem to display the thermal signature of swirling disks of hot matter, possibly gas about to be sucked into a black hole. The X-ray telescope also re-

Charting a more cautious path to space

Its reputation sullied by a string of ill-starred space projects—including the shuttle *Challenger*, the *Hubble* telescope and most recently the Astro observatory—the National Aeronautics and Space Administration seems soberly resigned to undertaking some sweeping changes. And a report recently released by a committee convened by Vice President Dan Quayle aims to show the space administration how to begin shaping up.

The report, prepared by a 12-person committee chaired by Martin Marietta chief executive Norman R. Augustine, proposes that NASA reorder its priorities and reorganize its internal administration. The report represents "a lowering of aspirations to match reasonable budgets and to create stability in the program," notes John M. Logsdon, who directs the Space Policy Institute at George Washington University.

The document argues that space science missions should rank on the top of NASA's priority list—"above space stations, aerospace planes, manned missions to the planets, and many other major pursuits which often receive greater visibility." The committee did reaffirm other NASA goals such as the "mission to planet earth" project, which is aimed at monitoring environmental conditions.

The group tempered its support of a manned mission to Mars by cautioning that the program "should be tailored to respond to the availability of funding, rather than to adhering to a rigid schedule." Specifically, the report called for a simplified, modular space station designed for studying life sciences in space, an exploratory base on the moon and more emphasis on robotic exploration of Mars. "This report is not a vote of no confidence in the space station—just in the one that NASA was planning," Logsdon says.

The committee also urged NASA to devote more energy to developing space technologies—notably new rocket engines. With unmanned, heavy-lift vehicles, NASA could reduce its reliance on the shuttle and build a "high-confidence, reasonable-risk" transportation system, the report said.

Apart from the call for reinvigorated space sciences, the committee did not propose new goals for NASA, points out Vice-Chairman Laurel L. Wilkening, provost at the University of Washington. Instead, she says, the group tried to advise NASA on how to accomplish its existing goals. "There was a perception that NASA was trying to do too much," Wilkening says, "so we tried to set out the logical sequence of things" to help NASA construct a program that would gradually build up the technology for a Mars mission.

NASA has neglected critical steps, Wilkening charges, including studying the effects of microgravity on living organisms. "No one doubts we could send a machine to Mars and bring it back," she says. But "almost no one thinks we know how to get a person to and back from Mars safely. The life-support research hasn't been done. NASA has not accorded this area of study the importance it must have."

Whether the space station and, eventually, a Mars mission will be delayed if NASA revises its plans along the lines suggested by the report is uncertain, Wilkening says—particularly because NASA was hazy in describing to the committee how well developed space station designs currently are. At this point, "it's not practical to put a date on a mission to Mars," she adds. "Even if you spend a lot of money, it's not clear you'll have the technology" to go to Mars.

Just how much weight the committee's suggestions will carry remains to be seen. The most telling sign, Logsdon points out, will be the White House's next budget proposals, slated to be released in early February. "You're not going to see money for another shuttle," Logsdon predicts. Still, he expects NASA may receive as much as a 15 percent increase, including a "healthy budget for the space station."

In spite of the Augustine committee's emphasis on space sciences, it did not call for dramatically increasing the funding for science. "The percent of the budget devoted to science is probably right," Wilkening says. "It definitely shouldn't be squeezed." By calling for administrative reforms, however, the report aims to improve NASA's efficiency and stretch existing dollars further.—*Elizabeth Corcoran*

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turned a wealth of as yet unexamined data on the structure and composition of objects ranging from distant clusters of galaxies to relatively nearby cataclysmic variables, exotic double stars in which a white dwarf cannibalizes its more sunlike companion.

The ultraviolet instruments on Astro scrutinized many of the same objects as the *BBXRT* but at somewhat less energetic wavelengths. The *Hopkins Ultraviolet Telescope* (*HUT*), the largest of the Astro instruments, peered at various quasars and active galactic nuclei to search for expected brightness peaks at ultraviolet wavelengths. Splicing together ultraviolet and X-ray spectra should provide clues about the nature of these enigmatic objects. *HUT* also searched for evidence of neutrinos with mass, one possible constituent of the dark matter in the universe.

A more specialized device, the *Wisconsin Ultraviolet Photo-Polarimeter Experiment* (*WUPPE*), searched for ultraviolet radiation polarized by interactions with ionized gas or interstellar dust grains. Preliminary indications that the dust causes very little polarization are consistent with the theory that it is composed of graphite. *WUPPE* will help astronomers understand other polarized objects, such as magnetic white dwarfs and blue supergiant stars.

The last instrument, the *Ultraviolet Imaging Telescope* (*UIT*), has an unusually wide (40-arc-minute) field of view. It recorded populations of hot young stars in other galaxies and confirmed the existence of galaxies whose output is dominated by radiation from a huge spasm of stellar births. Other targets included evolved stars in globular clusters, whose appearance should help nail down the exact age of these extremely ancient stellar conglomerations.

But the follow-up work evidently will not be done by Astro. Theodore Gull of Goddard, the mission scientist for Astro, tries to put a sunny face on the situation. "This is the NASA can-do spirit coming back," he proclaims, noting that the astronauts on the shuttle were able to react to problems far more quickly than ground controllers could have, had Astro been a free-flying satellite. He also asserts that as an independent satellite the observatory would have cost roughly $500 million, an amount that probably never would have been allocated.

Even so, Gull admits that the lack of a follow-up mission is "frustrating." Other astronomers tend to be less restrained. "It's a terrible waste," Davidsen laments. "It is hard to see how discarding a payload like this is really the best solution to NASA's problems."

Some participants still hold out hope. "The science is so strong that I think the situation will turn around," says Theodore P. Stecher, also at Goddard, who helped design and build the *UIT*. Given the erratic schedule of recent shuttle flights, however, the prospects are none too bright. "This is a loss for us, but more it is a loss for NASA," sighs Serlemitsos. Meanwhile he is working on a similar X-ray telescope for a future mission known as Astro-D. In an all too familiar sign of the times, Astro-D will be launched by Japan.—*Corey S. Powell*

Hubble bags a great white

The Great White Spot, an enormous storm raging on Saturn, was discovered by amateur astronomers in late September. Since then, it has grown rapidly and has spread across nearly an entire hemisphere of the planet. Beginning November 9, astronomers turned the *Hubble Space Telescope*'s wide field/planetary camera toward Saturn to take a closer look.

Previous *Hubble* images had established that computer-image processing could enable the telescope to achieve its intended resolution of about 0.1 arc second for relatively bright, point-like high-contrast targets. Many astronomers were pleasantly surprised to discover that the computer techniques worked equally well for an extended object like Saturn. The resulting image shows a startlingly transformed planet whose turbulent features now resemble those seen on Jupiter by the *Voyager* probes.

The spot's white color is probably caused by high-altitude clouds of ammonia ice crystals, but the underlying reason for the atmospheric upwelling that produced the clouds is unknown. Similar but smaller spots have appeared before, at 27- to 30-year intervals, hinting that these are seasonal features somehow linked to Saturn's 29.5-year orbit around the sun.

Two images, one taken in blue light and the other in infrared, were combined to produce this false-color picture. Blue indicates low-altitude clouds; red identifies higher-lying ones. Already *Hubble* has collected more than 400 images, which will be used to create a time-lapse movie of the Great White Spot's behavior. —*Corey S. Powell*

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Safe Bytes

What it will take to keep computers secure

Well-publicized incidents involving hackers, "worms" and computer viruses have called the integrity of computer networks into question. Yet the threat of cyberpunks breaking into these pervasive electronic links is not the worst one that computer users face. "More information has been lost or damaged by mistyping, power failures and software errors than by all the break-ins and all the computer viruses ever unleashed," asserts Eugene H. Spafford, a researcher at Purdue University.

That's why computer cognoscenti are trying to redefine security: not just computers that keep out unwanted visitors but ones that users can trust implicitly. A panel of experts assembled by the National Research Council puts software quality control at the head of a list of "Generally Accepted System Security Principles." After all, if programmers can't be sure a piece of software will function properly under normal conditions, they can hardly claim it will be secure against attack.

The new holistic approach to security places an emphasis on computers that will perform properly under any kind of adverse condition—hardware failures, software errors, misuse or malicious penetration. "If a [computer-controlled] medical device kills someone, whether the flaw was accidental or intentional is irrelevant," says computer scientist Peter G. Neumann of SRI International, who was a member of the National Research Council panel.

Ironically, rapid progress in computer technology has left security concerns far behind. The Internet, for example, is an international research network that connects about 315,000 computers in more than a dozen countries. A year and a half ago, a "worm" program infected more than 6,000 computers on the network, about 10 percent of the total then connected. Public outrage was widespread. But by the end of 1990, at least a fifth of network sites reportedly had yet to fix the software loopholes that gave the worm access in the first place. Meanwhile the number of viruses and other destructive programs that infect computers is growing. The general level of awareness for network security, Neumann says, "is pitiful."

Some computer networks are fairly

Superconducting transistors show their speed

Engineers seeking practical applications for the new high-temperature superconductors have been frustrated by a phenomenon called magnetic flux creep. In strong magnetic fields the supercurrent moves the flux lines. This creates electrical resistance, so the materials cease to be superconductive.

Now researchers at Sandia National Laboratories and the University of Wisconsin at Madison have cleverly exploited that effect to build high-speed transistors. And they have incorporated them into circuits that outperform similar conventional devices. Applications could come in "a year or two," says David S. Ginley, a member of the Sandia team.

The new device, known as the superconducting flux flow transistor (SFFT), was initially developed by Wisconsin researchers including Jon Martens, who has now moved to Sandia. The SFFT consists of two regions of a thin film of high-temperature superconductor, joined by a dozen or so even thinner "weak links" of the same material.

The weak links, 0.1 micron thick, are arranged like the rungs of a ladder. A magnetic field from a superconducting control line can pin or unpin flux lines in the weak links of the SFFT and so shift them between a conductive and nonsuperconductive state. "The ultimate speed of the device depends on the speed of the flux lines, and once you kick them loose with a magnetic field, they move very fast," Ginley says. He expects that the devices should be able to operate at 100 gigahertz (100 billion cycles per second).

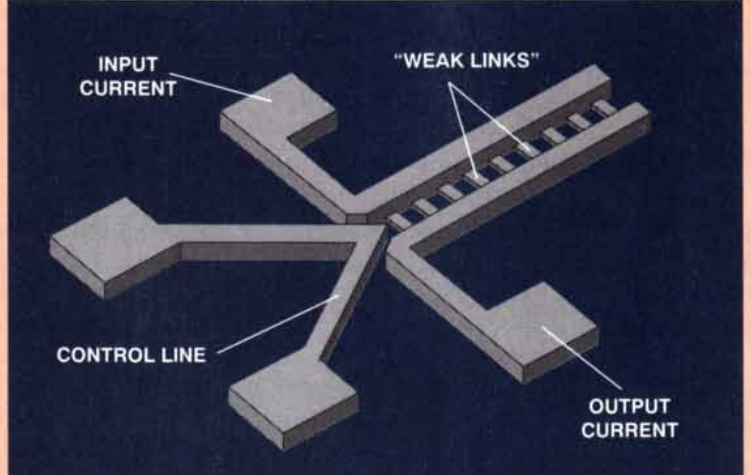
Most SFFTs have been made with thallium calcium barium copper oxide. That material holds the record for losing its resistance to electrical currents at the highest temperature, 125 kelvins, but other ceramic superconductors work, too. The biggest obstacle to making devices has been achieving uniform film quality, but up to 10 SFFTs can now be built on a wafer with confidence, Martens notes, by using electron-beam evaporation followed by sintering and annealing.

So far the Sandia researchers have built such SFFT devices as microwave amplifiers, oscillators, phase shifters and signal mixers. Microwave circuits now measuring several square feet might ultimately be replaced by a single SFFT chip, Ginley predicts, who expects improved phased array radars and infrared sensors to be among the first applications.

The Sandia researchers have also built digital logic devices using the SFFT. One possibility is that SFFTs could act as interfaces between Josephson junctions—very high speed superconductor switches that are difficult to link up with conventional electronics—and gallium arsenide semiconductors, thus bringing ultrafast Josephson computers a step closer to reality.

—Tim Beardsley

A SUPERCONDUCTING TRANSISTOR



Current passing through the control line creates a magnetic field. This causes the weak links to lose their superconductivity, blocking the flow of current and "switching" the device.

well secured. The Athena campus-wide net at the Massachusetts Institute of Technology, for example, relies on two different kinds of encryption for passwords and data, and it is resistant to attack even from computers on the network that have been subverted by a malicious user.

That offers little help, however, for the average personal computer user. The software that operates on personal computers is generally designed on the assumption that anyone sitting at the keyboard should be able to access any information stored in the machine. Security is very difficult to add on after the fact, and so the situation for PCs, although not hopeless, "may be bleak" according to panel member David D. Clark of M.I.T.

There isn't much incentive for manufacturers to do better. The federal government has no security standards for computer networks, so verifying security claims is difficult at best. Furthermore, U.S. export-control regulations discourage manufacturers from building in encryption subsystems, a key security ingredient.

Meanwhile some computer researchers contend that technology will never provide a foolproof fix for what they see as an essentially social problem. Peter J. Denning, former president of the Association for Computing Machinery, predicts that "normal laws and peer pressure," not encryption or other complex techniques, will eventually bring computer security problems under control. Spafford notes that parents today teach their young children that it is socially unacceptable to dial numbers at random simply because the telephone network is out there. In the future, he says, "we need to educate kids that you don't write viruses, you don't snoop in other people's files."

Others are taking a stronger line, including some who would consider making some kind of license a prerequisite for network access. "We're certainly moving in that direction," says Lance J. Hoffman, professor of engineering and applied science at George Washington University. He likens the process to the evolution of automotive regulations: "In some states, a five-year-old can drive a tractor because you can do anything on your own farm. But once you get out on the highway—or the network—you need a license."

In the meantime the social and technical state of the art will advance largely in response to well-publicized mishaps. "You don't learn how to ride a bike without falling off," Spafford comments. "I just hope there are no really huge disasters." *—Paul Wallich*

Nuclear Numbers

Living near power reactors may not add cancer risk

The nuclear power industry's moribund state is proof enough—if proof were needed—of public apprehension about nuclear safety. One frequently voiced fear is that low-level radiation from nuclear plants may cause cancer in local residents. When British researchers in the 1980s found higher than expected numbers of leukemias among children who lived near nuclear reprocessing plants, those worries seemed to be justified.

Several recent studies of the cancer incidence near U.S. and French nuclear plants, however, find little evidence to confirm the data from the Sellafield, England, and Dounreay, Scotland, facilities. "At least we know in large measure that we are not underestimating the risks and that we probably are overestimating them," insists Jacob I. Fabrikant, a radiation physicist at the University of California at Berkeley.

In France, Catherine Hill and Agnès Laplanche of the Gustave Roussy Institute examined deaths from childhood leukemia near six nuclear sites over 19 years. The study, published in *Nature*, concludes there is no evidence that living near any of the sites increased leukemia risk. "This increases our confidence that radioactive waste around such installations is not a significant worry," says Sir Richard Doll, a University of Oxford epidemiologist, best known for establishing the link between lung cancer and smoking.

Yet the French study makes the leukemias at the British sites more puzzling. One possible explanation is that Sellafield discharged more radioactive waste than any French plant. Then, too, even when an apparent excess of cancers is detected, radiation need not be the cause. One rare leukemia is caused by a virus, for example.

In the U.S. the National Cancer Institute conducted a large statistical study that compared deaths in 107 counties adjacent to or with nuclear sites with deaths in 292 nuclear-free counties. That study found "no evidence that an excess occurrence of cancer has resulted from living near nuclear facilities," according to an oversight committee.

The study came under fire from antinuclear activists because it dismissed an apparent excess of childhood leukemia near one nuclear site: the Millstone power plant in New London County, Conn. John D. Boice, Jr., one of the report's authors, justifies the decision by explaining that "although the rates were high, they didn't vary by distance from the plant." Boice also observes that there was already a high local incidence of leukemia before the plant started operation.

Critics were also quick to point out that the study might have missed many cancers because of its use of large geographical units and because it analyzed cancer mortality rather than incidence. "Most—if not all—of the nation's nuclear facilities have not been operating long enough to cause cancer deaths," argues Michael Mariotte of the Nuclear Information and Resource Service in Washington, D.C., an antinuclear group.

An investigation by Maureen C. Hatch of Columbia University School of Public Health and others, supported by the Three Mile Island Public Health Fund, did use incidence data—and produced some unexpected results. The study, published in the *American Journal of Epidemiology,* found that lung cancer and non-Hodgkin's lymphoma were more common among people likely to have received the highest radiation doses from the plant, during the 1979 accident as well as normal operations.

Nevertheless, Hatch and her colleagues decided radiation was probably not the culprit: non-Hodgkin's lymphoma is thought not to be easily triggered by radiation. Lung cancer is influenced by smoking, but the authors do not know how much their subjects smoked. Leukemia and thyroid cancers, in contrast, which are known to be radiation sensitive, were no more common than normal.

The one study that bucks the trend was conducted by the Massachusetts Department of Public Health. It concludes that before 1984, people who lived close to the Pilgrim plant in that state had an almost four times higher risk of acquiring leukemia. Few outside epidemiologists are prepared to defend the conclusion. According to Richard Wilson, a physicist at Harvard University, the findings are confounded by abnormally low leukemia rates some distance from the plant and by the arbitrary exclusion of some data.

Despite the lack of a smoking gun at nuclear sites outside Britain, studies will continue. And the interpretation of the results will probably continue to be controversial. "One in five people in the U.S. dies of cancer, against which we're trying to discern a very, very small signal," says Kenneth L. Mossman, who studies radiation health effects at Arizona State University. But for now, Fabrikant concludes, "our science and our approach seem to be supported by the information in these studies." —*Tim Beardsley*

SCIENTIFIC AMERICAN

Special Advertising Section
February 1991

SWITZERLAND:
Partner in Perfection

Special Advertising Section.

The EC, Switzerland and Swiss Trade Fairs.

Philippe Lévy, Director General, Swiss Industries Fair, Basel.

Switzerland is situated in the very heart of Europe, surrounded almost entirely by EC territory. But—and this is the main question today—has Europe (or more precisely the EC) conquered a place in the hearts of the Swiss?

The answer is still pending. The discussion in full swing is whether to join the EC, whether to join the EES (European Economic Space)—on condition that the negotiations are successful—or to stay apart, risking to find oneself one day in an isolationist solo.

In our opinion, the Swiss are sensible and hardly inclined to fall prone to mere window dressing. The equality of the conditions of competition among EC and EFTA countries—as the EES option might offer—certainly leaves quite a lot to be wished for. But it would, nevertheless, be a possible compromise. But which future will the Swiss have? Shall they be the "last Mohicans" of a vanishing era of sovereign nation-states in an integrating Europe? Asking this question might today seem far from realistic. But keeping in mind that most of the EFTA states have already applied, or are about to apply in due course for admission to the EC, the trends are unequivocal. And January 1, 1993, the date when EC members will complete development of a Single Market, is approaching very quickly.

For the principal Swiss trade fairs, the question whether Switzerland is going to join the EC or not is a crucial one. Any negative answer to this question cannot eliminate the disadvantages of location. What that means is this: for the Swiss Industries Fair Company (our country's most important fair site—one need only think of the European Watch, Clock and Jewellery Fair), the complicated and time-consuming task of customs declarations for the purpose of proof-of-origin will burden foreign exhibitors in Basel even after national borders within the EC have gone. Additionally, the Basel Fair Company receives no state support, neither in respect to the administration of its real estate nor the organization of the trade fairs themselves.

Keeping in mind this situation, the Basel Fair Company is about to look for new ways and means in order fully to preserve its attractivness within an extensively changing environment.

One solution might be the creation of a second, complementary fair center near the French and German borders with Switzerland (but within EC territory) through a trinational effort on the part of both public and private entities. Such a project would be the first truly international fair site, because supported by three countries. It would, therefore, be a model of the United Europe concept. It might also answer to the general, new orientation towards a regional Europe, and indeed help to establish an important bridge between the Europe of the EC and Switzerland.

March 2– 11	75th Swiss Industries Fair
March 2– 11	Natura 91, 12th Exhibition for Healthy Living
March 21– 24	3rd Swiss Solarmobile Show, with 7th Conference on "Solarmobiles in Everyday Use"
April 13– 17	KAM 91 International 32nd Art and Antiques Fair of Switzerland, with international participation
April 18– 25	Basel 91, 19th European Watch, Clock and Jewellery Fair
June 12– 17	Art 22'91, 22nd International Art Fair (20th Century Art)
June 12– 17	Edition 2/90 Basel The International Fair for Contemporary Original Prints

Special Advertising Section.

Added value for international competitiveness.

Jean-Pascal Delamuraz, Federal Councillor.

Switzerland's prosperity depends to a high degree on the competitiveness of its economy. We are a small country of 6.7 million people, half of our national income depends on our export of goods and services. Also, an important contribution is made by successful, market-oriented technical innovation. In our country, full employment and prosperity are closely bound up with technology and economic management.

The 1980s were marked by fundamental technological changes which had to be converted into successful marketing strategies—and at increasing speed. International technological competition has been becoming ever more intense. This has been reflected in economic enterprises focusing increasingly on research, and in higher research budgets at both government and company levels in almost all industrial countries.

The Swiss economy can maintain its international competitiveness only if it attaches priority to obtaining a high level of added value per production unit, and uses its capital and know-how with maximum intensity. It must become a powerhouse of added value.

The traditional strengths of our economy, and the opportunities available to it, lie in pronounced customer-orientation, concentration on market niches and specialized products, high quality standards, precision, promptness of delivery, plus advisory and maintenance services. In the technological race, we must convert new techniques into high-quality responses to market requirements. This process must include the integration of conventional systems and methods in the fields of mechanics, electronics, information technology, sensor engineering and material science.

The aim of Swiss industry must continue to be the creation of sophisticated technology which combines—and integrates—traditional skills with new techniques. Our first priority must be combi-tech, i.e. bringing together high, middle and low tech in the most creative way possible. The most important governmental contribution to maintaining and promoting technological competence throughout the economy is the provision of an efficient and adaptable elementary and higher-level training system.

It is the task of government to develop and stimulate cooperation between training and research bodies on the one hand, and the economy on the whole on the other—and this on a permanent basis. In view of our limited resources and the critical dimensions required of projects, government promotion of research aims at creating an increasingly sharp focus on clear-cut market orientation.

The Swiss reply to the technological challenge consists in ensuring our "technological competence". Our liberal system of government guarantees the existence of conditions conducive to technology and innovation. It is for the private economic sector to make critical judgments on the technological options as carefully and quickly as possible. And then apply those decisions with resolution.

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Special Advertising Section.

Audemars Piguet: Small company, big name.

Steve Urquhart, Co-Chief Executive Officer.

Georges-Henri Meylan, Co-Chief Executive Officer.

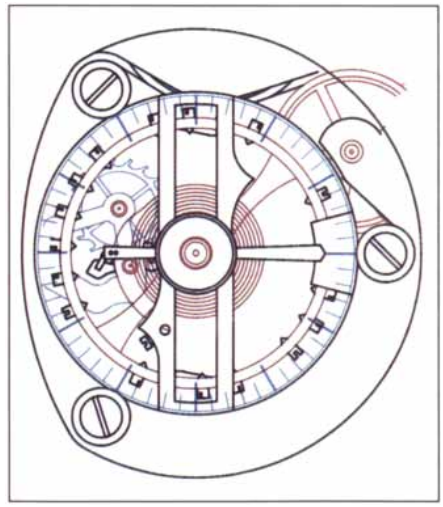
When the master-watchmaker founders of Audemars Piguet joined forces in 1875, their first effort was the "Grande Complication". It was—and still is—a pocket watch of twelve functions. But only two a year are made nowadays, still at Le Brassus, up in the high-altitude Vallée de Joux. Their more than 500 hand-finished parts are encased in 18-karat gold. Price? Roughly half a million Swiss francs each.

The very same carefully husbanded tradition animates the design and making of Audemars' approximately fifteen thousand watches a year, the tiniest fraction of the Swiss watch industry's output.

Each one represents the perfected intersection of hand-work and computer-aided design. Amid milkcows and the preternatural tranquility of meadows, state-of-the-art CAD is applied in the service of skills more than a century in the making.

Audemars is now as always: a family-owned company—the inheritance of descendants of the men who began in the very same place more than a century ago. Its watches, made by a mere 220 people (60 in a micro-mechanical and electronics subsidiary), today descend a single-lane asphalt road to Geneva airport (only 65 kilometers away) to waiting clients worldwide—but especially in Japan, Italy and Hong Kong. And why so many customers from Japan?

Explains CEO Steve Urquhart, sixteen-year veteran of the Swiss luxury watch trade, "I am convinced we represent just that intersection of values which they treasure—on the one hand, precision, and the other, tradition. Something about those who appreciate the kimono—they seek to own an Audemars Piguet."



CAD rendering of a tourbillon escapement, invented two centuries ago. In 1986, Audemars introduced the first self-winding tourbillon wristwatch.

"The States is still lagging behind. We find that 55% of our output goes to the Far East, just 15% to North America. This is a situation we are, of course, working to change."

AP
Audemars Piguet®

Technical bravura has long distinguished the company. When others farmed out assembly to specialists, Audemars and Piguet resisted sub-contracting. Still pioneering, in 1986 it was Audemars Piguet which first perfected the microtechnology of the *tourbillon* system (invented by Breguet in the 1790s)—to eliminate errors of rate in the vertical position.

The firm stays close to the austere, specialist high road of mechanical watches. "People love the interaction of winding the instrument," says Urquhart, "to see that their touch recharges its energy. It seems something alive, an extention of yourself." What makes an Audemars tick for a hundred years is not an integrated circuit, but its precision parts—assembled, adjusted and regulated for maximum performance. The emphasis: durability and reliability. That is why they command an average retail starting at $10,000.

And the latest Audemars—the Dual Time? "We plan to make only 700 a year for sale worldwide, with about twenty percent going to the States.It is an automatic watch and, if fully wound for 48 hours, says so on the dial. As well as the time in another zone, and the date. It is not so much what we are showing on the face of the watch, but what has to be done inside—quite invisible to the eye—to show it. The challenge is in creating a microtechnical, non-electronic system.

But to get a mechanism inside that translates into a hand on the dial—reporting how much the watch is wound—that is also a high technology."

ONLY THE FEW WILL OWN AN AUDEMARS.

Classic Straps: Automatic with date and second-hand in 18K gold.

Perpetual Calendar: Day, date, month and moon phase in 18K gold.

Dual Time: Automatic with date, power reserve and two time zones in 18K gold.

Only the few will seek the exclusivity that comes with owning an Audemars Piguet. Only the few will recognize more than a century of technical innovation; today, that innovation is reflected in our ultra-thin mechanical movements, the sophistication of our perpetual calendars, and more recently, our dramatic new watch with dual time zones.

AP
Audemars Piguet

Only the few will appreciate The CEO Collection which includes a unique selection of the finest Swiss watches man can create. Audemars Piguet makes only a limited number of watches each year. But then, that's something only the few will understand.

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Special Advertising Section.

Nestlé: Global strategy, for the long term.

Helmut O. Maucher, Chairman and CEO.

A scientist in white lab coat studies a tray of mosses and algae samples, grown in vitro. "It seems to have proved a dead end," he explains in English slightly accented by his native Norwegian. "To isolate the bacteria retardant we are after is one thing, but to generate it in the volumes called for, something else." The scientist's training is world-class; his equipment better than most universities. And his microbiologist's task is to identify those plant-origin agents which can slow, or stop, the spoilage of fresh food. Meals ready-to-heat, for example, shipped to refrigerated cases in supermarkets. He is looking to replace those unloved "classical" stablizers which both his own corporate management—and the public which buys Freshness brand fresh entrees in the US—find are not "natural" enough.

He works at the Nestlé Research Center at Vers-Chez-les-Blanc, not simply the world's largest but also its leading institution dedicated to food and nutrition research.

Almost five hundred such scientists and technicians from thirty-five countries work here, spending an annual budget of about SwF 100 million; they labor in near-utopian lab surroundings that cost SwF 200 million to build and another 75 million to equip, set amid the greenery outside Lausanne. And they work not by any means simply to make Nestlé's Quick or Stouffer's frozen entrees sell more in America or Nescafé in Japan or ice cream in France and Brazil. Instead, they are "up" (or perhaps "back") several steps from the grocer's shelves, seeking to understand nothing less than the relation between what we eat and our well-being.

Take calorie and fat reduction, the number one concern in those industrialized countries where world-girding Nestlé does the lion's share of its business. The target? Not only to make foods that can be labelled "light", but to understand the structure and behavior of ◗

The Nestlé Research Center in Vers-chez-les-Blanc, near Lausanne.

lipids so as to create new "multiple emulsions" and new food systems based on natural ingredients. "We want", explained one researcher, "that mayonnaise-type product with only a low percent of fat in it to taste as creamy and satisfying as the standard product. Success will mean doing well by doing good; defining "natural" means to protect the freshness and nutritional value of foods, but also to develop ones that stop worsening our affluence-induced problems of cardiovascular disease, diabetes and obesity. The Center aims for product improvement indeed. But also for patents and knowledge for itself.

Nestlé's spending here is only about a fifth of its R&D spending overall, now up to a half billion Swiss francs. That translates into about 1.1% of turnover. The multinational food industry average is about 0.7%.

Dr. Werner Bauer, professor of food process engineering at the Technical University in Munich, heads the Center. "We are not isolated here, as can happen in a university. Our emphasis is in four strategic areas: food science, food technology, bioscience and plant science, and two preventive research areas: nutrition and toxicological risk assesments." Another example of the Center's current work? Bauer: "Nestlé processes a tenth of the world's green coffee beans. That generates a wax which, heretofore, had been a waste product. We want to take that substance, which cost money to get rid of, and turn it into something of value for use in the cosmetics industry."

"We study slow release starches, the sort that can stop dependence reactions in diabetics. And also the role of yogurt cultures in strengthening the immunological status of elderly people. The Center is studying new approaches to avoiding food allergies. The old strategy was getting rid of allergenes, but we want to know how to process foodstuffs so that even when the allergenes are present, the biosystem is blocked from recognizing them by 'marking', thus defusing their negative effect."

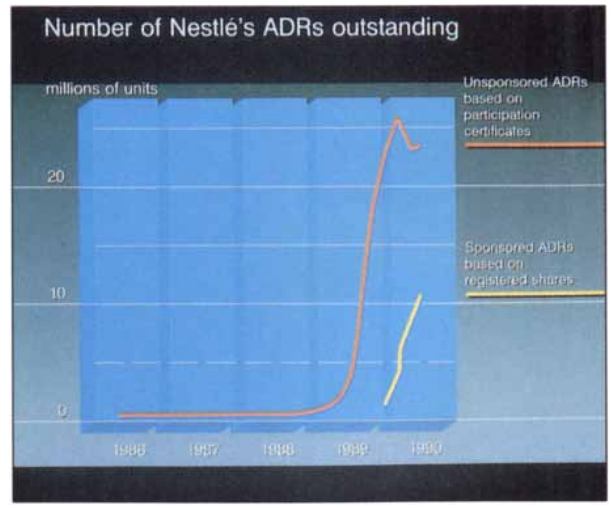
"In nutritional science, we have moved from classical metabolistic studies to working on the whole man through non-invasive methods using stable isotopes, a more realistic approach than working only with animals. Overall, this Center is ever more oriented to strategic issues, not only to matters of food technology and processing."Vers-chez-les-Blanc is the tip of an iceberg, a kind of crown jewel.

At 125-years-old, Nestlé is one of the world's largest industrial companies, with 197,000 employees and 421 factories in 61 countries. Nestlé fills the world's market basket: drinks (coffee, tea, cocoa, juices, mineral water, wine), milk products (22% of sales) and infant foods, chocolate and confectionery (16% of sales), culinary products (soups and boullions), canned and frozen food, desserts, fresh cheeses, packaged meat, pasta and pet foods. The company was able—and willing—to quadruple its R&D investment over the past decade because sales more than doubled.

Reto F. Domeniconi, Executive Vice President for Finance, Control and Administration, mildly understates the case: "Food is resistant to downturns." Figures comparing 1988 to 1989 show Nestlé's net profit up 17% to a record SwF 2.4 billion.

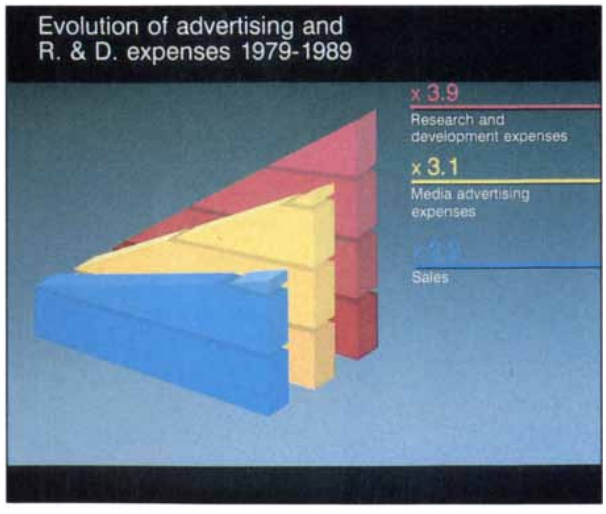
It was Domeniconi who brought his firm's "ADRs" to the New York Stock Exchange, successfully increasing "ADRs" market capitalization 50% over the past two years to a staggering $20 billion (SwF 1.30=$1), ten times earnings (as of March 1990). Today, Americans are the largest single group of Nestlé owners after the Swiss.

What is an "ADR"? A bank buys a Nestlé registered share, puts it in its deposit and issues one hundred "American Depositary Receipts", instead of the share. The security is thus divided into one hundred units and that one-hundredth sells for, say, $50 rather than



$5000. The ADRs are what is called "pink-listed"—these are daily quotes of non-listed stocks. Today more than 24 million Nestlé ADRs are outstanding in the US, valued at more than $700 million.

Domeniconi: "It takes very long to change the image of a company in a market. In international financial circles, we had no image until a few years ago—and to the extent we did, it was that of a so-called 'granny stock'. We are still not sufficiently far from that misconception. This has to do with our very conservative financial policy: low leverage. We used to feel ill at ease with any net debt, but we now have about SwF 5 billion in debt, having crossed that line when we purchased Carnation [for $3 billion]."



"Then we bought Buitoni Perugina [$1.2 billion], as well as the UK-based Rowntree [$4.5 billion], and we remain in some debt. And we like it that way. We focus on an increase in earnings per share, which means avoiding dilution. This will push up the share price, and with it the multiple—making us always more raider-resistant." Despite such costly acquisitions, Nestlé has retained its triple-A debt rating.

"As for our pay-out ratio to shareholders, that was 25% and it is now 30%, in the medium bracket in Europe. I think we will never go as far as US firms do, paying out at levels of 40-50%."

Nestlé does all this because grounded in some of this planet's most famous brands. Camillo Pagano, a forty-year Nestlé man, Executive Vice President and member of the ten-member management committee, estimates it would cost SwF 25 billion to establish a Nescafé world-wide, starting from scratch today.

As a kind of "boss of the brands", what is Pagano's perspective on a food company that some years introduces as many as one hundred new products? "The mass market is dead; segmentation and individualism are in. There is no average consumer, no average store. We take the soluble Nescafé and position a new usage—for young people who like to drink cold rather than hot. We are generalizing the use of iced coffee shake. This is the case of a one-brand product (Nescafé) that tastes different in each country—young people in Greece, France, Germany are using Nescafé to make a Nescafé shake. Or take the case of our chocolate milk modifier Nestlé Quik. It has become what I call "a wardrobe of a brand", *i.e.* it is avaiable in ready-to-serve packs and in the form of an ice cream bar. Our Milo brand, in Asia: a candy bar, an ice cream stick and a powder to pour in milk for a fortified tonic drink. We bought Rowntree for its brands, such as Kit Kat and After Eight. It is these—the brands—which are the most valuable, intangible assets of a company. Yes, the consumer wants choice and price, but he also wants to be assured and reassured of consistency and quality. The brand does that."

He continues, "Every case at Nestlé is different. For us, the key lies in regional and national marketing specialists, with brand managers who stay ▸

and know their territories. And backing up production and marketing, our unique "RECO" system (from "REsearch Company")—twenty technological development centers in ten countries, employing 2100 people—each with a multitude of professions such as food technologists and test kitchen staff, located near factories. Our Nordreco, in Sweden, developed peas that are disease resistant. In Spain, we work on tomato varieties that will retain their flavor and fresh taste whether they end up fresh, dehydrated or frozen, whether in a sauce, a condiment or a pizza."

Under Chairman and CEO Helmut O. Macher, the company has taken some daring marketing initiatives. A deal has been struck so that all food presence inside Euro Disneyland, to open outside Paris in 1992, shall be only Nestlé. Pagano: "The parks' restaurants inside may buy ingredients as they like. The park's choice locations will be connected with the Nestlé corporate logo and image. We want to concentrate on what we know and do it to the best of our abilities: we are marketers of branded goods and transformers of raw materials. We are not in agro-business—no cows, no plantations; nor the packaging business—no manufacturing of glass bottles and no supermarkets. We sell sauce to Pizza Hut, French fries to McDonald's in Canada and the US. Our food-service customers do not want us in competition with them. At the Paris park, the branded products will be Nestlé alone. In addition, under license, the company will develop a line of new items connected to the Disney venture. We are not saying we will launch a Donald Duck breakfast cereal. But we can use the Disney characters and no one else can. Chocolate products, certainly. It is an arrangement I would call 'made in heaven'."

But breakfast cereals are very much in Nestlé's present and future. A 50-50 venture has been launched with General Mills, called Cereal Partners Worldwide (CPW). Explains Pagano, "We decided, a bit late, to enter the breakfast cereal business, which is one of the fastest growing food segments worldwide. General Mills was not marketing outside the US, where it is very successful. They wanted to participate in what, in the US, is called 'Fortress Europe', and we have the network and the deep country knowledge. Again, an excellent match; the arrangement was assembled in nine days. CPW's first priority is Europe. Its potential is excellent: other countries outside the US are adopting this nutritional habit, *i.e.* the breakfast cereal habit. That means Cheerios can be the same worldwide. By the way, the products outside the US will carry the Nestlé parentage: Nestlé Golden Grams and Nestlé Honey Nut Cheerios."

(L. to R.) C. Pagano (General Manager, Nestlé), R. Fitzpatrick (President, Euro Disneyland), Mickey Mouse, D. Hightower (Vice President, Walt Disney Products, Europe and Middle East), R. Masip (General Manager Europe, Nestlé).

Special Advertising Section.

Patek Philippe: The Craftsman's Hand as Precision Instrument.

Henri Stern, President.

Philippe Stern, Managing Director.

What does it signify to be the oldest independent, family-owned watchmaker in the world? It means that 400 craftsmen in Geneva, and high in the mountains of the Swiss Jura, work on every single component of a Patek Philippe. Every part is hand-finished. It means that a Patek Philippe is not an assemblage of the many bits of a watch, bought from suppliers.

The result is something the firm calls "as near perfection as humanly possible", a mere 15,000-or-so timepieces a year, with the average price of a man's watch roughly fifteen thousand Swiss francs (approximately $11,000). One must put this in the context of an industrial product made in the millions, and especially in reference to some famous Geneva-based brands making well over 500,000 pieces *per annum*. Patek, then, makes its movements and its cases–but is also invents. As recently as 1985, the firm patented the Date-of-Easter mechanism built into the extraordinary Caliber '89 astronomical clock-watch. It was five years in the designing by four watchmakers, four years in the making; the first of four examples sold at auction (April 1989) for 4.5 million Swiss francs.

The craftsmen of Patek made the Caliber '89–"the most complicated portable timepiece ever": 1.1 kilograms, 24 hands, eight discs on two main dials, 1728 parts. But Patek's staff—last makers of specially commissioned engraved pocket-watches—also make watches sold and worn world-wide.

For example, the "La Flamme" line for women, or the Golden Ellipse models (available with a unique blue-colored gold dial), or the Nautilus—a sportwatch in gold, gold-and-steel or all steel. The most popular of all is the round-shape "Calatrava" (first created in 1932) model for men and women, 18-karat gold with small second hand and classic case. Patek Philippe's 150-plus year tradition is no less in these than in the Caliber '89. And Patek Philippe has a long connection with the United States. The firm was founded by a Polish emigré to Switzerland, Antoine de Patek, in 1839. Six years later, he had been to New York and found his major customer, Tiffany & Company. They are a customer, a Patek source still.

PATEK PHILIPPE
GENEVE

Watch with perpetual calendar, minute repeater and florally engraved 18-karat gold case, silver dial.

Reverse of the "Packard watch", with star chart. Sold in 1927 to James Ward Packard of Warren, Ohio.

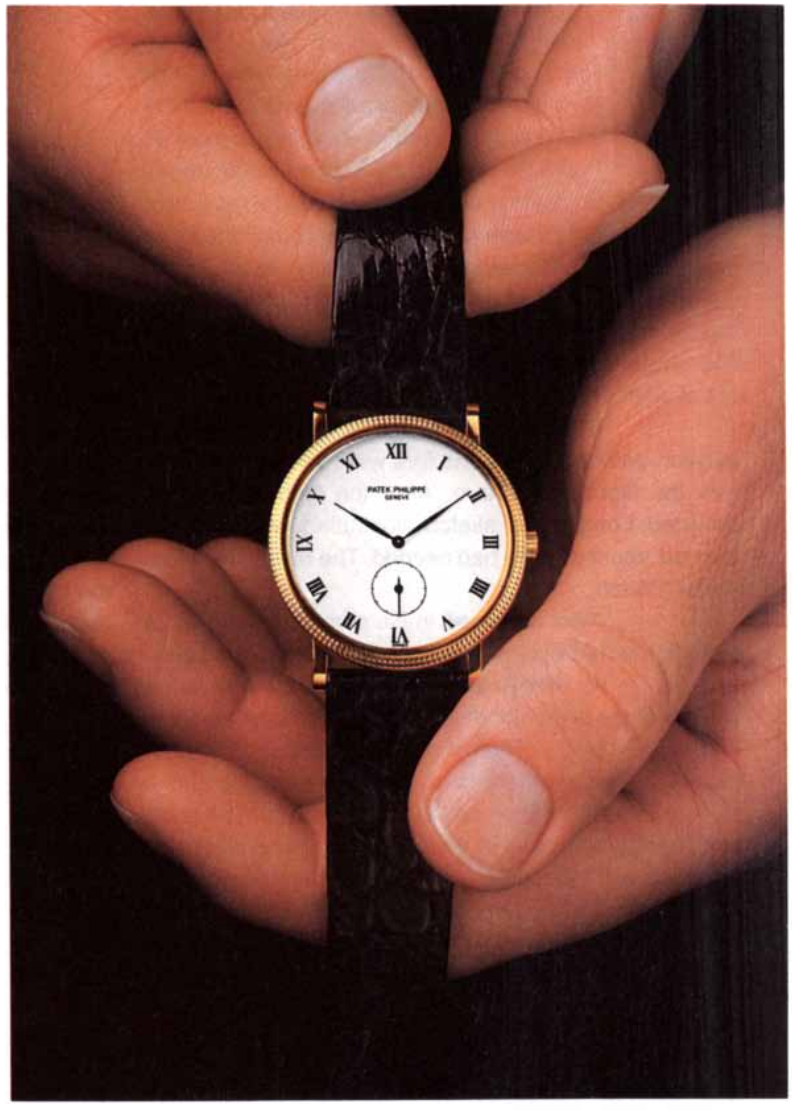
Watch history followed: the world's smallest watch, exhibited at the Crystal Palace Exposition in 1851. At the same exhibition a gold, enamel and diamond-set pendant-watch was purchased by Queen Victoria. In 1910 came a watch with a five-gong Westminster chime, then (in 1925) the first perpetual calendar wristwatch. Famous watches for famous wrists: Rudyard Kipling, Albert Einstein, Marie Curie. In 1956, the company produced the first-ever all-electronic quartz clock and in 1988 bought back the famous "Packard watch"(see illustration)—sold in 1927 for SFr. 12,000—but now worth more than two million.

The arts of the Geneva watchmaker by Patek Philippe. Look on a Patek's movement and find the seal of the Canton of Geneva, conceded only to those who meet strictest standards. The firm's achievements are on view, as works of legend, in Geneva's *Musée de l'Horlogerie*, the renowned watch museum. Or a Patek Philippe can be worn, to be used and enjoyed every day.

WHEN you first handle a Patek Philippe, you become aware that this is a watch of rare perfection.
We know the feeling well. We experience a sense of pride every time a Patek Philippe leaves the hands of our craftsmen. For us it lasts a moment — for you, a lifetime.

We made this watch for you — to be part of your life — because this is the way we've always made watches.

And if we may draw a conclusion from five generations of experience, it will be this: a Patek Philippe doesn't just tell you the time, it tells you something about yourself.

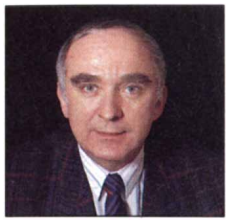


PATEK PHILIPPE
GENEVE

For current informative brochures please write to:
Patek Philippe, 10 Rockefeller Plaza, Suite 629 (SA), New York, NY 10020.

Special Advertising Section.

Longines: From the "Winged Hourglass", more than a century of fidelity.



Walter von Känel, President.

Two historic names—Charles A. Lindbergh and Longines—connected by a key event of our time. The aviator left New York for Paris on May 20, 1927, aiming to be the first to make the transatlantic solo flight nonstop. His achievement (it took him a mere 33 hours, 30 minutes, 29.8 seconds) depended on his instruments: he needed what he did not then have—a watch that functioned as a navigational aid. Knowing the precise time, in relation to Greenwich, would allow for calculating the longitude of the "Spirit of St. Louis" and would permit measuring the hour angle in degrees and minutes of arc, when flying out of sight of land.

The head of Longines in the US was an aviation enthusiast, and the firm went to work even before the flight's departure. After the flight, Lindbergh provided Longines a sketch illustrating what he had learned about what he had needed. The result: the "Hour Angle" Watch.

The original, in the company archives, is gigantic—a massive and impractical 47.5 mm diameter.

In 1987, to commemorate the 60th anniversary of the flight, Longines re-introduced the model in 4/5 scale—a family of them, including a true chronograph (allowing measurement to a fifth of a second) and a women's version. They are available with a mother-of-pearl center dial, case in gold or steel, concave mineral glass, brown lizard strap—design of the period.

The company, based as always at St. Imier in the Jura (and, as ever, famous worldwide) expects few to acquire the Hour Angle strictly for use in aerial navigation. But collectors will flock for the limited edition of 1000 in the steel model, 100 for those in gold.

LONGINES®
TIMES THE WINNER
A company of SMH

Many of the "Hour Angle" will go to Americans. Longines' president Walter von Känel explains, "My goal is to strengthen the brand image worldwide, increasing market share, further improving our distribution channels and unified image. We have the advantage of stability of management, and that has given us a chance to benefit from the move up the learning curve."

"Longines began doing business in the States almost immediately after its founding in 1889. Along with Japan and Italy, the US market is a key one for us. We make specific models for America: for example, the Longines 400, the 1000 and the Gold Medal. And, of course, the Rodolph, the Lindbergh Hour Angle and our new world-wide line, Conquest—now in its 'third generation', launched in October 1990."

Longines calls the Conquest "the watch of the future": whether in steel, steel-and-gold plate or titanium and gold plate, its "Futurity" quartz version offers a VHP (Very High Precision) movement, accurate to one minute in five years. Its perpetual calendar—powered by an electronic micro-chip (developed by the SMH Group's EM Microelectonic Marin company)—adjusts for months of 28, 30 and 31 days and for leap years. Virtually perfect, until February 28, 2100.

SMH

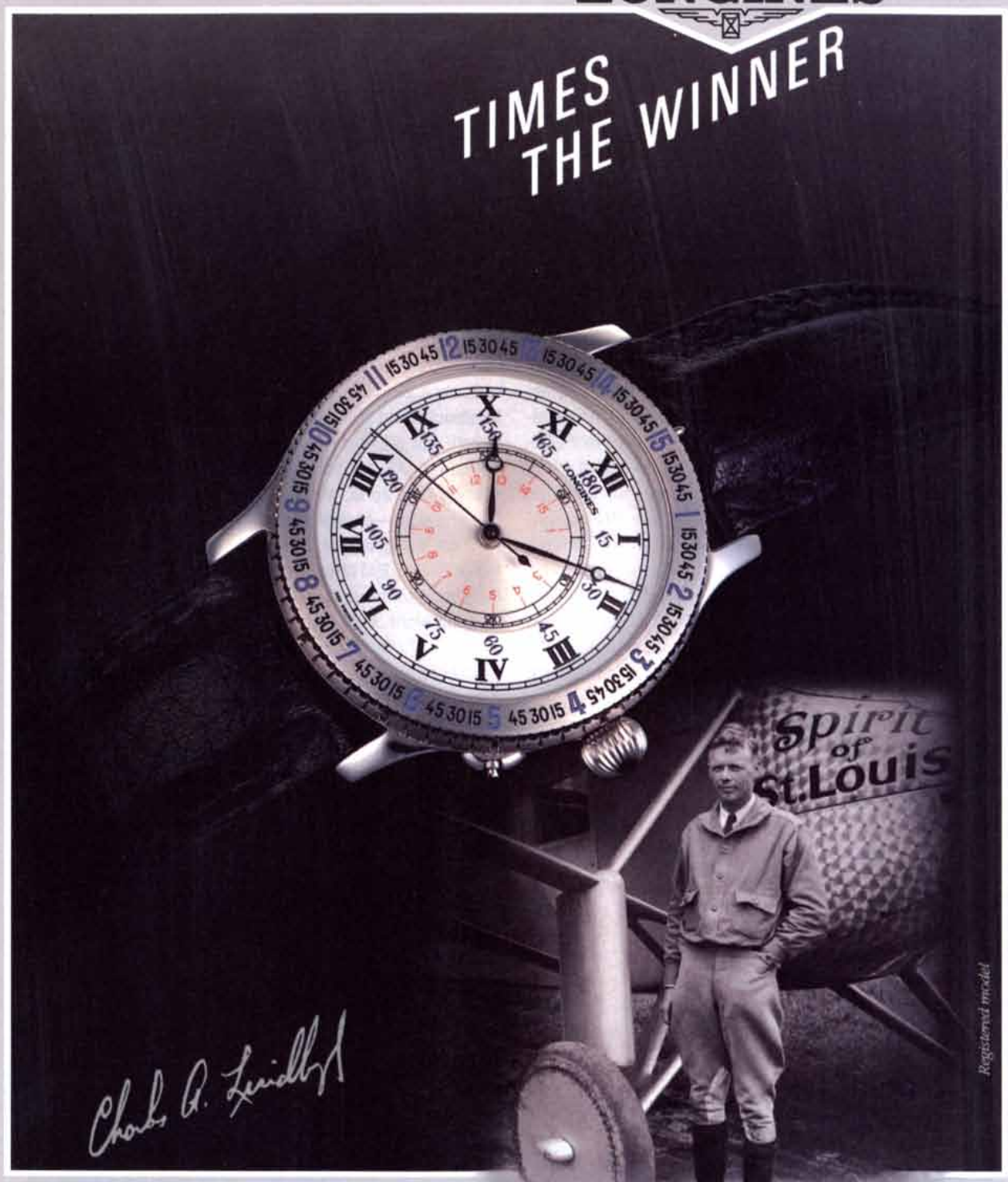
EM Microelectronic Marin: 'Low Power' is their business.

The SMH Group (properly SMH Swiss Corporation for Microelectronics and Watchmaking Industries Ltd.) was born in the mid-Eighties to "save" the national industry from Japanese inroads. A holding company led by Chairman and CEO Nicolas G. Hayek, it is a model of vertical integration: at one end, the Group's ETA company is the sole non-Japanese world supplier of watch movements (the other two are Citizen and Seiko). ETA is the *nec plus ultra* master of quartz technology, and supplier to almost every watch brand we know.

Electronics are centered in a group of SMH firms: Micro Crystal, Oscilloquartz and the sector leader, EM Microelectronic. A range of watch brand companies—marketing entities—carry the products to retail all over the world. Here the articulation has been carefully made along price lines. At the top-end, Omega and Longines, with a special niche for Rado. In the middle, Tissot and (in the US) Hamilton,

LONGINES®

TIMES THE WINNER



In steel. Large model. Replica of the original, 4/5th actual size. Self-winding movement. Available also in 18 ct. gold and steel/gold.

The celebrated Longines Hour Angle navigational watch, made by Longines to a design by Charles A. Lindbergh, who completed the first solitary non-stop transatlantic flight in May, 1927.

Today, people going places, as well as those who have already arrived, still rely on Longines for the elegant approach to their timekeeping needs.

LONGINES®

Longines times winners – winners choose Longines

Special Advertising Section.

Omega: Building on tradition.

Hans Kurth, Executive Vice President.

Their names echo across the decades, memory's roadmarkers to their epoch. They are brands that signify quality, elegance, reliability—all that goes to make for status. The "Seamaster", of course, and the "Speedmaster". Who does not know them? They mean Omega, the maker whose mechanical, hand-wound precision instrument (called a "watch") was worn on the arm of every US astronaut on every US mission. "Every man who has been on the moon has worn a Speedmaster Professional," explains Executive Vice President Hans Kurth. "Those are significant moments for mankind, and that is also the theme of our world-wide advertising message."

In 1990, Omega launched a line derived from this moon-going model, a range from an automatic, mechanical to an ultra-complex moonface chronograph, including ladies' models in gold and steel-and-gold.

And why mechanical movements, and not quartz? Hans Kurth: "Mechanical watches have worked for decades, for hundreds of years. Quartz simply has not yet reached that age. We have quartz movements now that are just twenty years old. The jury is still out."

"This is still a luxury watch; even in steel only it retails at around $1000. There is no market for such a precision instrument at a lower price."

Omega is far from offering only watches in the grand, old mechanical tradition. Take its "Constellation" line, available in models both automatic and quartz, in a variety of metals, for both men and women.

Or the "Seamaster Multifunction", retailing for about about $800. It looks like a conventional two-hand watch, but as you turn the crown it starts to act like a computer. All the functions of a stopwatch, a timer, a second time zone, alarm, second and minute and hour, day and date—all legibly displayed in black, thanks to an LCD on the gold dial. Perfecting the technology was the job of SMH's EM Microelectonic Marin company. Making the precision beautiful, with 18-karat gold inlaid in steel, was the work of Omega.

Vice President Kurth acknowledges the brand has lost some ground, and now faces a challenge. "We were diffused, offering perhaps too many models. Now we are focusing again: that meant eliminating the 14-karat gold watches. That also means we have reduced from two thousand retailers in 1985, to half that number now, and the number is still dropping."

"Our strategy is that every consumer who acquires an Omega be convinced that he has an absolutely first-quality, top product. As a brand, either you are upmarket or not. Now, in the States, this upgrading process is well underway. It is a complex re-positioning exercise in which we stop being everything to everybody, but in phases. We will, with time, drop all the watches at the lower end of our product range, adding new models at the top end."

Ω OMEGA

A company of SMH

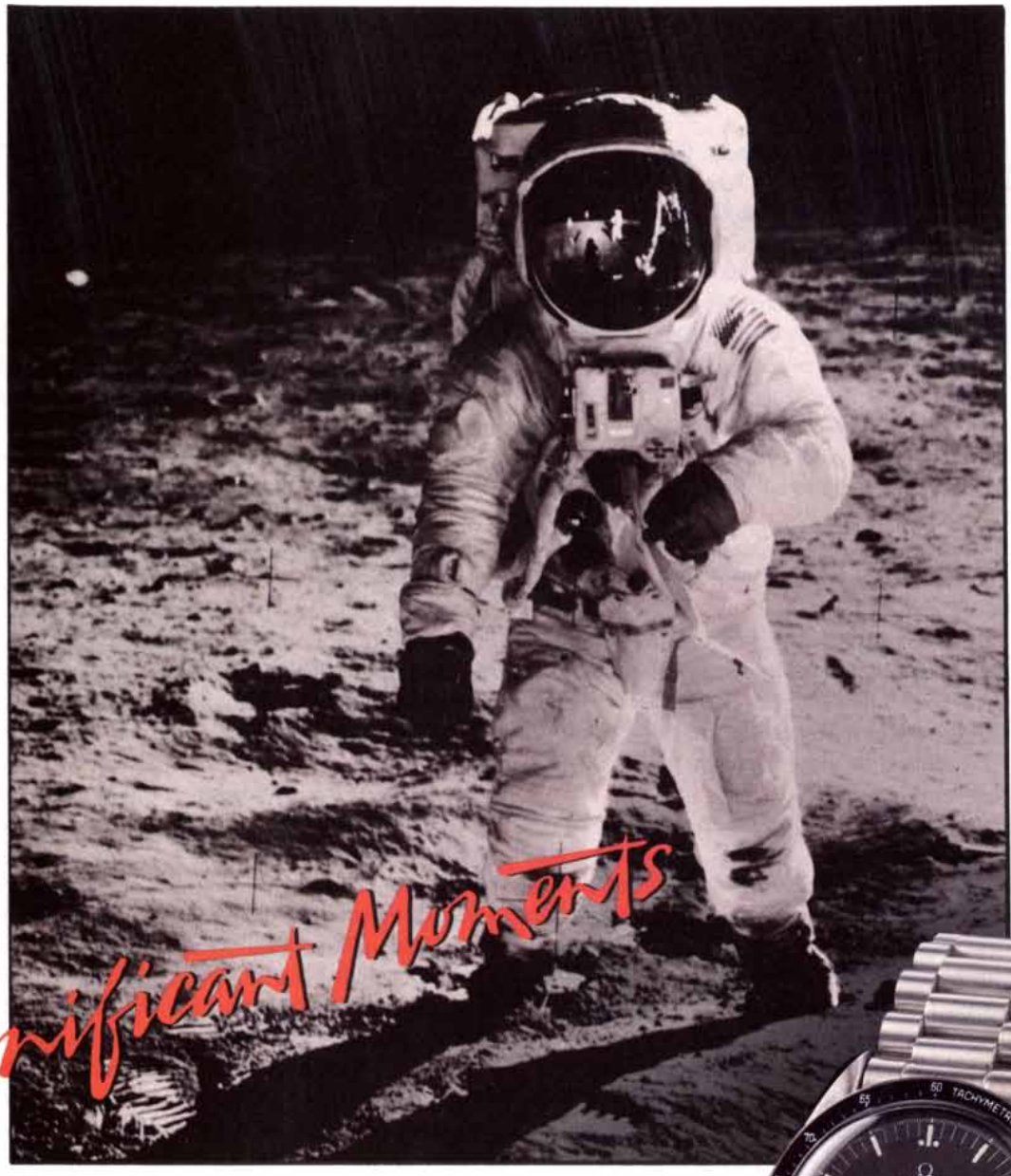
as well as Balmain, Certina and Mido. At the lower-priced segment, Swatch—which one "grows into" after Flik Flak, called "the Swiss watch for children". Backing all this, production systems companies, components and precision parts suppliers and services (sports timing, data handling and transmission, R&D, patents). All under the growing SMH umbrella.

From 1988 to 1989, net income of the holding company grew 20.7% (to 64 million SwF) and consolidated income of SMH Group (the brands and connected activities) increased an amazing 66%, to 175 million Swiss francs.

The heart of the watch is the movement, and at its heart is an electronic brain. "That is what we developed and now manufacture," explains Mougahed Darwish, president of the Group's EM Microelectronic Marin S.A., "that integrated circuit which is powered by the battery (from the Group's Renata company) and redistributes that power to the quartz from SMH's Micro Crystal, and to the display. That integrated circuit (an IC) is the watch's brain".

In the case of an analog watch, like a

« IT WAS A MOMENT OUT OF A DREAM. WHEN THE STEP OF A MAN TRANSFORMED THE HISTORY OF MANKIND. OMEGA. FOR ALL OUR SIGNIFICANT MOMENTS ».



OMEGA. The watch that records the world's significant moments. At the Olympic Games. In outer space. And exclusively for you. Here is the Omega Speedmaster Professional in stainless steel.

Ω OMEGA

Special
Advertising
Section.

Rado: Making space-technology beautiful.

Roland Streule, President.

Roland Streule, Rado's chief, reflects on his company's latest achievement—the genuinely innovative DiaStar "Ceramica". And why did no one else use ceramics for a scratchproof watch before? "Most watch companies work with materials that are easier to handle, the traditional metals which are so readily available. But Rado has always taken a pioneering line. We were experienced with the so-called 'hard metals' like titanium or tungsten carbide (used to cut steel), and man-made sapphire. The ceramic existed, of course, but lacked characteristics we required: not enough surface polish, too breakable, the colors were wrong and the surfaces not scratchproof.

RADO
Switzerland
A company of SMH

We went to work with that SMH company specialized in computer components, and we consulted French experts, and had contacts in the US and Japan. The challenge was to make ceramic parts—both small and thin. To achieve this, our suppliers had to develop special machinery.

We started first with an inlay to hold the ceramic links of the bracelet together. Its prototype was steel, but we thought it too heavy, not desirable next to the skin. Then we went to a composite, but it stretched in testing. Now we have it absolutely right: steel for tensile strength, imbedded inside the ceramic parts. The result is wrist-hugging, anatomically comfortable, visually perfect—and secured with a triple safety clasp.

The cover of the buckle is also of high-tech ceramics. Its assembly is a very delicate matter of sliding, of combining with an adhesive. For the mirror-level polish, only diamonds for cutting and abrasion are hard enough. This gives this watch its spectacular "soft touch" finish.

Already in 1986, we launched the Integral, the first watch with a bracelet made of high-tech ceramics. But it was possible only in an anthracite color, kind of charcoal. Now, with the Ceramica line, we have a fully scratchproof ceramic watch, including the case, crown, bracelet and buckle. The high-tech ceramics we use are those tested in dozens of NASA space flights; not a matter of a simple powder, but the use of 'zircon-Y', produced from zirconium and yttrium oxides. The result is a watch that looks as beautiful after years of use as it did on its first day.

The difficult part was to put together the ceramic case with the man-made sapphire crystal, using high-temperature bonding. Part of the solution was a completely new adhesive, one that had to be waterproof and invisible. How was it done? First, a metallization is put onto the sapphire crystal, which then is bonded onto the ceramic case. But the powerful adhesive must not dilute the metallization. Such is the technology that had to be hidden, all to make a streamlined, elegant design.

Since we wanted the perfection of a fully ceramic watch, how could we leave the crown in steel? Together with our specialists, we developed something ▸

Swatch, the power goes to a motor (made by ETA); one of the contributions of EM to Swatch was perfecting the IC so that energy dispersal was smoother. The watch "rests" between movements of the second hand, and that made the mechanics quieter. In the case of a multifunctional Omega Seamaster Professional, the power passes through the IC and serves both liquid crystal display (LCD) and hands.

The key is a double one: miniaturization and "low power". EM's integrated circuits consume about 100 nanowatts, and one nanowatt is 10 to the ninth place of a watt, or below one microwatt. Darwish calculates that a 60-watt lightbulb, lit for one second, would run an EM integrated circuit for ten years.

"For assembly miniaturization, we have developed a specific technqiue called tape automated bonding (TAB): it is the smallest possible package, reducing the wrapping to the dimension of the silicon itself. We became leaders in this technology under pressure to make watches ultra-thin."

EM is free to sell outside SMH, and sees ▸

which is traditional inside, and over it, a ceramic cap."

Streule points to the watch's "radical" design: "The traditional idea, of course, is some sort a head with a strap, or bracelet that looks well with it. Here, we wanted one piece. In fact, our goal was a beautiful bracelet with a timepiece attached, the idea of the watch as jewelry. It took time even for us at Rado to become accustomed to the idea of a watch looking like this. It was, but only at first, somehow 'too' different from the usual. Even inside the trade, some were nervous. But we found the response among the buying public overwhelmingly positive, especially in the States, right from the introduction in August 1990. Even more than in Europe, where the watch is very well accepted indeed.

Where a Rado Ceramica watch begins.

Usually, the watch industry—at least in design terms—is characterized by small steps forward and backward, the re-working of the round watch, mixing material a little differently. But rarely a giant, new step in design or materials. Every engineer knows that round is the easiest, and therefore the least expensive shape to manipulate in manufacturing. Rado had the courage to leap.

To us, the Ceramica is a piece of jewelry that accurately reports the time, and not a timekeeper which one tries to make as beautiful as possible. We have, and quite consciously, subordinated the functions to the overall power of the design—and not the opposite. But we have made a watch to be worn every day, something durable. It is truly scratchproof because made of one of the hardest material on earth.

Our initial launch was about 100,000 pieces, a lot for a product in this category. After a Japanese test—and they are very quality-demanding customers—we introduced in Switzerland and Germany. After that, the US and Canada.

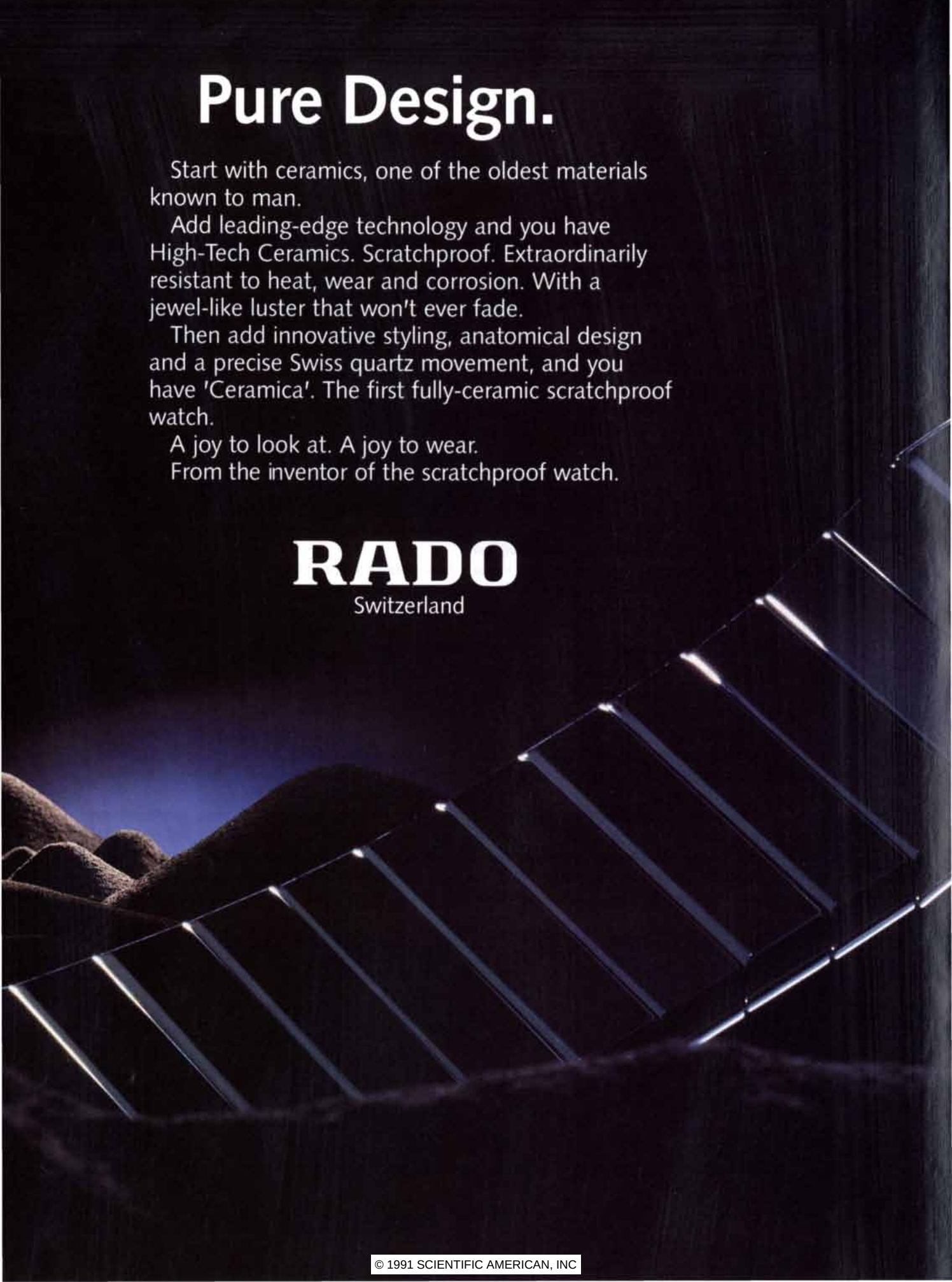
Yes, the majority of US consumers are traditional in their taste. But there are groups interested in differently looking products, a group which appreciates the special in design and technology.

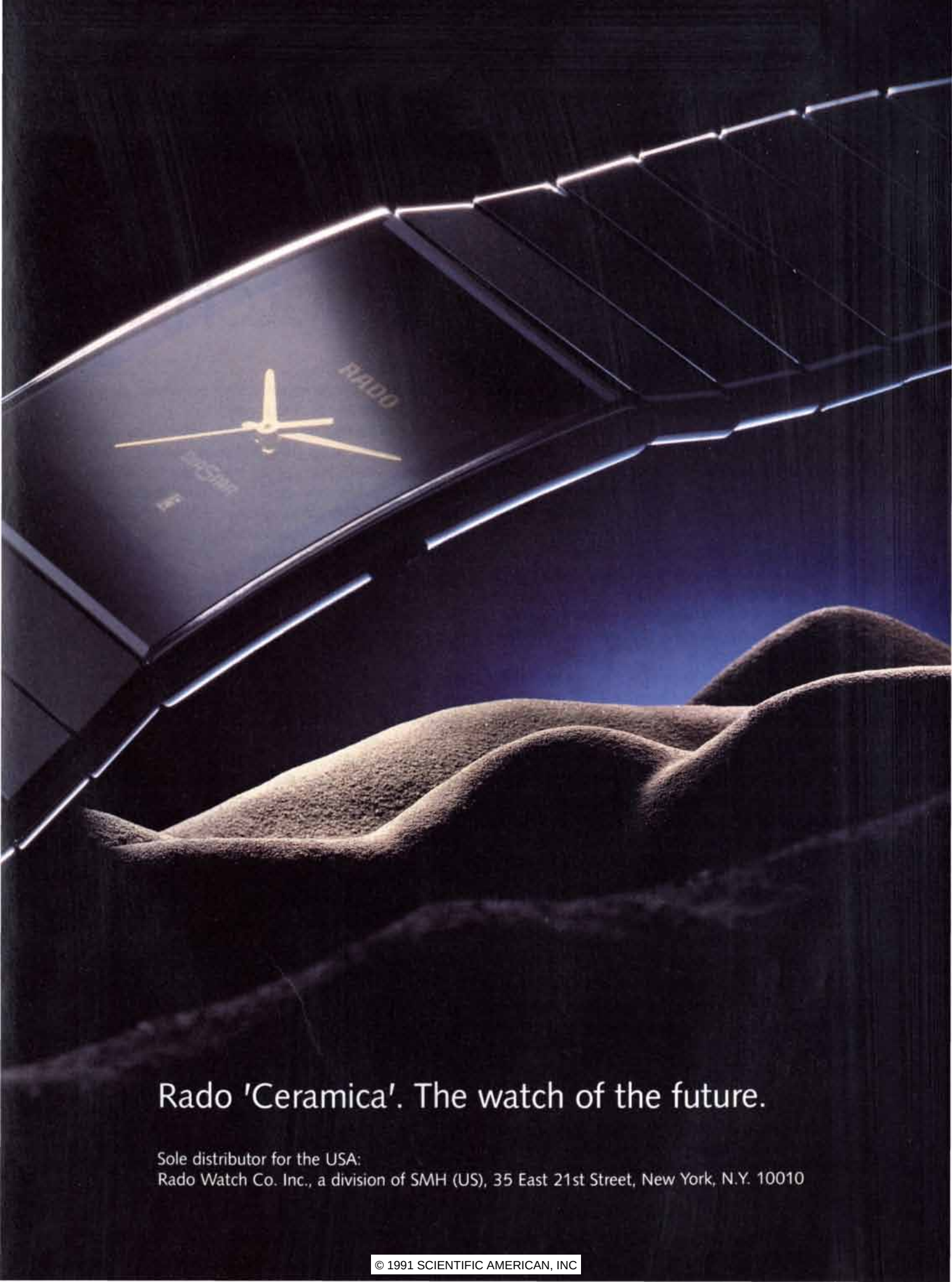
It would not have been so difficult to produce the Ceramica at a 'fantasy price'. But our goal was to hold at $1,000-$1,500—a good price/performance ratio—and we have reached it. And we have realized our strategy: 'one material, one design, one concept.'"

many non-watch applications for its know-how. Darwish: "There is a general interest in very low power and very small size. Our TAB assembly technique has been licensed to INTEL. What we have mastered is the production in high volume, 65 million chips a year."

EM's staff of 360 (almost 50% graduate engineers in design, process development, process sustaining) see a growing customer list. Thanks to EM's ultra-thin LCDs, wide angle contrast is possible and that delivers crucial high visibility. Applications? Medical photography, where the LCD acts as a high-speed (less than one millisecond) shutter.

When EM's miniaturization prowess is combined with low power, one has portability. The watch, after all, is a portable instrument. But so are pacemakers, hand calculators, hearing aids, cathetic-based micropumps that record consumption and electronic toys. In fact, all those industries which need measuring and display through ICs. From EM Microelectronic, high-tech that was born for the brain of a watch, to an almost limitless range of products.





Rado 'Ceramica'. The watch of the future.

Sole distributor for the USA:
Rado Watch Co. Inc., a division of SMH (US), 35 East 21st Street, New York, N.Y. 10010

Special Advertising Section.

Swatch: "Synonymous with originality and fun".

H. Jürg Schär, President.

swatch®

A company of SMH

How to develop, manufacture and sell 75 million watches in seven years, starting from ground zero? First, have a brilliant concept. An all-plastic product built around a technology you know intimately and control. Then, develop winning designs and virtually perfect quality control; make the watches so that fewer than 2% are returned under warranty. Then, market with a touch of genius. The SMH Group set out to do it this in 1983, and since then the world has been saying (as on MTV and the mainline TV networks), "I Swatch very much".

The technology is in the quartz movement, brought to an absolute state-of-the-art by the SMH Group company called ETA, maker of over sixty million watch movements a year. Swatch's manufacturing, also ETA's job, is a model of automation; now down to a handful of workers who intervene on those rare occasions when the machines (working non-stop virtually seven days a week) malfunction.

To reach its price target, Swatch needed to handle the movement differently. This used to be separate from the case, something inserted into it. The Swatch movement is built in. No one else does that. Swatch has simplified: usually, a watch consists of about 150 components. The Swatch counts out at 56.

It also helps to develop fantastic, eye-catching models and keep changing them—some merely brightly-colored, others almost surreal. To succeed, commission artists like Keith Haring. And maintain close control over retail price and sales outlets.

And always, always, bring to market a product at less than one hundred Swiss francs (that is about US $70). Over 90% of the watches sold in the world retail at, and under, that price.

Jürg Schär: "Swatch has three product offerings, of which two we market ourselves: first group is watches, the second telecommunication products. The third, which others will manufacture and market, are licensed products under our name."

"In watches, part of our success is that when we started, in '83, we concentrated on two shapes only—a model for men and one for ladies. We played with the design, not the features. It is when you get to millions of units, as we did quite quickly, that you spend—and we did—on very expensive automated processes, where labor is a small portion of total cost."

Seemingly omnipresent in Europe and getting that way in the US (Swatch has started at J.C. Penney, Mervyn's and college bookstores, while continuing in the high-end department store chains), the brand sees territory yet to conquer. Schär: "In Switzerland, which is unrepresentative because of the intensive tourist market here, we sell well over 100 watches for every thousand inhabitants. Our penetration is 28 per thousand in Italy, 12 in the US. We see substantial prospects in South America and in the Far East. And that is to say nothing of all of Eastern Europe."

How to keep winning? Offer new features. In 1990, the company launched the Swatch Scuba, waterproof to 200 meters, at $50, the least expensive watch with such features. It will roll-out in 1991 in 36 markets.

Starting with Europe, Swatch has introduced a watch quite complex by any standard. It is a real chronograph and, says Schär, "...so far, demand has outstripped supply." It will become available in the U.S. (at about $80) this year, very accurately reporting the time in seconds, minutes and hours. And function as a stopwatch.

And Swatch telecom? "In '88 came the Twinphone, our entry product. It is partly manufactured in Taiwan, but engineered and designed for us by ETA,

Just Imagine...

swatch®
there are no limits

here in Switzerland. It offers a real twin feature, allowing two individuals to talk and hear at the same time with the same phone." Its current US retail: an amazing $70. "In the last quarter of 1990, we brought to the States a Twinphone with two separate phone lines—it allows two different conversations on one apparatus because the base takes one line, the receiver another. In the future, Twinphone will have further features, like a built-in answering machine. The key here is that we shall remain a maker of telecom products for end-users, not for office use."

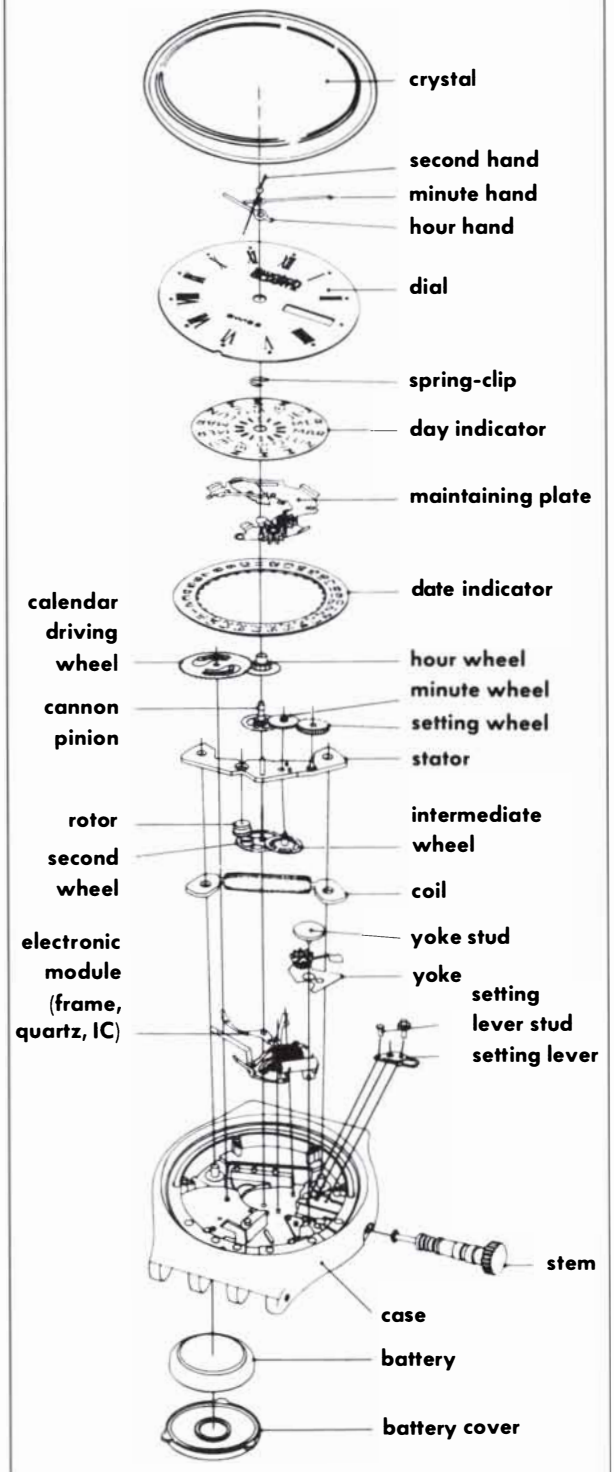
And the third leg of the Swatch strategy, the licensed products bearing the Swatch name? Schär: "We will not go an indiscriminate route. Rather, we will only license a product which enhances the Swatch image, and that means something visible and used every day. Possible Swatch licensed categories are sunglasses, leisure clothes, pens and stationery, sporting shoes, even toiletries. Excluded? Furniture and technical goods."

Schär expects the first licensed items this year, starting in Europe. What they must have in common with the Swatch product—whether the basic watch, the Pop Swatch (an over-sized fashion watch), the Scuba, the chronograph—are the characteristics of what the company calls "user imagery", its "attitude demographic". That means products for people seeking a good price/quality ratio, people who are "self-confident, sociable, humorous, unconventional, sympathetic, creative, spontaneous, self-deprecating, people who strive for quality in life, who are young at heart."

Late last year, an "early Swatch" (vintage 1983) sold at auction in Milan for $20,000. Says Schär, unfazed, "We are convinced that Swatch is not a fad, that there is not just a passing interest in plastic watches. Swatch seems to have become a reference point, something generic."

He is too modest. People are just starting to do what the company's ads call for: "Swatch Around the World".

swatch®



If your Swatch where to explode...

TWO PHONES IN ONE

One for you, one for me. One phone for two people, with a twenty memory name dial, last number redial button and it is also B.A.B.T approved. A range of phones that comes in lots of exciting designs and colours now available in leading stores. The Swatch Twinphone.

MORSE CODE

swatch®
twinphone

Special Advertising Section.

Sulzer Brothers: "The technology corporation of the Nineties".

(L) Pierre Borgeaud, Chairman; (R) Fritz Fahrni, President & CEO.

Sulzer Brothers Limited is nothing less than a world-wide technology group, carefully structured for synergy, but also differentiated and specialized. Headquartered for more than a century at Winterthur, the firm deploys about 1250 people in R&D at HQ—and over 2000 worldwide—about 8% of its total staff. In real operational terms, only about one-fourth the firm's turnover and one-fourth of its people are in fields that are *not* R&D-based. Sulzer's real business is technology.

For the Nineties, Sulzer is focused on what it calls its "key capabilities", centered in strategic business units. CEO Fritz Fahrni has cited the Building and Construction Services Group (SwF 1.5b turnover, 1989), the Sulzer Ruti Group (weaving machines, 1989 turnover SwF 1.1b) and Sulzer medica (grown to 600 billion Swiss francs), enlarged with the acquisition of Intermedics in the US. Sulzer sells almost everything it makes worldwide, with North American orders up a notable 49% from 1988 to '89, and sales invoiced up an even more impressive 39%. What can one pinpoint as the leading edges in a complex strong in a range from weaving machines to diesel engines and power plants? From thermal turbomachinery to hydraulics and compressors? From microelectronic-based medical systems to fine chemicals?

Richard Burger, member of the company-wide Executive Management, and responsible for Corporate Development, explains three areas where

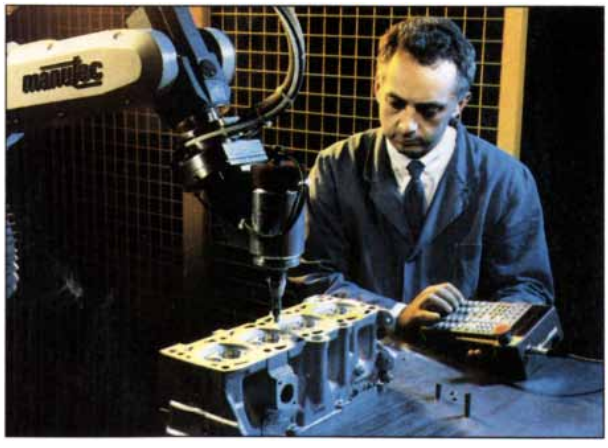
SULZER

Sulzer's "core skills" are at work, areas expected to grow into "pillars" of Sulzer in the coming decade:

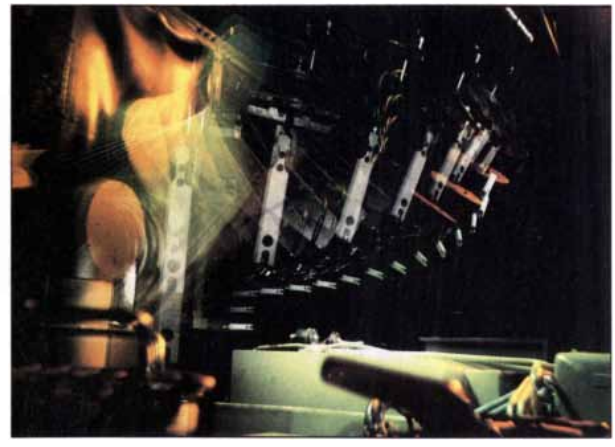
(1) *Sulzer medica.* Here more than half the research is conducted in the States. "We focus on durable implants, orthopedics and cardiovascular applications—hip-joints and knees, heartvalves, pacemakers and grafts. In cardiovascular, Sulzer has collaborated with the Swiss Federal Institute of Technology in Lausanne to develop an Incorporable Ventricle Assist Device, an implanted heart-assist pump with an external energy source. Our strength is in combining Swiss precision technology with US surgical experience. We are now in clinical trails for a dual chamber distributor pacemaker, of which the first implants have taken place in Switzerland. After seven years's study, we now see success in developing coated tubes of less than six millimeters diameter for the unclogging of arteries."

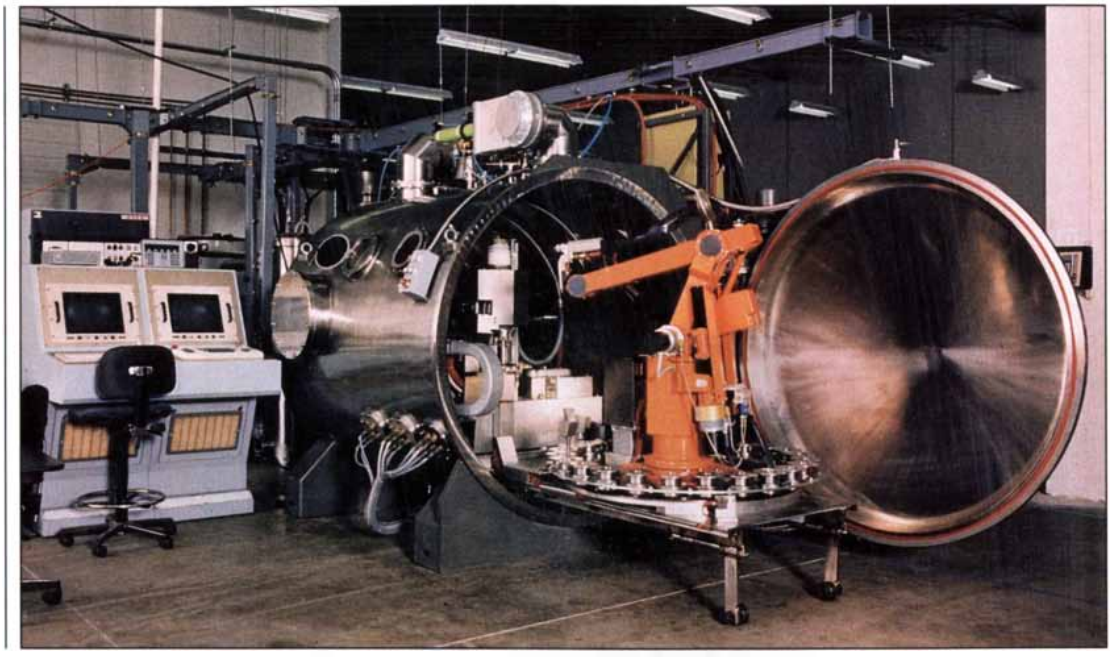
"Our orthopedic implants can also be custom-made, using 3-D CAD and numeric-control to manufacture parts, coated with hydroxylapatite, a material that simulates human bone and stimulates its growth. In the pipeline, a dental implant coated with the material which we expect to be the first to win FDA approval."

Industrial robots solve complex processing and handling problems.



Machining by robot of a weft insertion projectile in the Zuchwil works.





A fully automatic plasma coating system creates surface properties fit for heavy-duty applications.

(2) Surface technologies. In this field of growing importance in material technology, Sulzer has acquired particular expertise as a user of coatings in a vast variety of its products, as well as becoming a supplier of coating solutions, equipment and consumables. Sulzer Plasma Technik is a leading manufacturer of high-end plasma spray equipment for industrial production and in the R&D for plasma coatings. Burger explains: "every system is specially designed optimally to fulfill the specific requirements of the customer, i.e. of the aeronautic, automotive, energy-generating and medical industries."

Meuli total wrist joint replacement: Titanium-Aluminium-Niobium forged alloy.

So too with bonding and adhesives—Sulzer is engineering titanium alloys resistant to extreme wear conditions. "We are now deep in the researching of ceramic-containing composite materials which can be metallurgically bonded. This is done by laser-surface alloying."

"Another Sulzer strength in the surface technologies: paper-making machinery. The firm is at the forefront in recycling systems to generate pulp from recycled paper as "raw material", with a network of service centers for paper-producing clients in the States. "The cylinders on which paper is made are yards in diameter and need a special wear and corrosion resistant coating with optimized thermal conductivity."

It was with Sulzer's unique forming and pressing concepts that a machine in the US reached the world's highest production—some 2520 tons per day of "linerboard"—used in the outer plies of corrugated boxes.

(3) *Process engineering.* Burger: "We sell systems made out of key components designed and built by us, ones in which we hold patents. For example, in the growing biotechnology field, we are system-builder of fermentors—not the sort for brewing—but for genetic engineering, in which precision and control are paramount. We build them in Switzerland, sell them worldwide. Another case is cryotechnology, where we are very strong in big helium liquifiers. Clients come to us to solve problems of scientific application."

Sulzer-Chemtech's activities in the field of crystallization plants for bulk chemicals such as monomer, chlorinated and nitrited aromatics are well established in the US. Sulzer-Chemtech's Crystallization System, a solvent-free purification process, is used when very high purity products are required.

Emissions into the air and water have been reduced to zero, because the plants are designed as internally closed systems.

Indentifying new technologies and perfecting mature know-how—world-wide—that is Sulzer Brothers for the new decade.

Special Advertising Section.

"Winterthur" Insurance: Leaping national frontiers.

Peter Spälti, Chairman and CEO.

Peter Spälti ought to know a thing or two about organizations and their behavior. An enthusiastic staff colonel in the Swiss Army, he has been for seven years a member of the Swiss Parliament, representing the Canton of Zurich and serving on the defense committee and on the standing commission for foreign trade and economy. Since 1983, as CEO, and since 1989 also as board Chairman of the Winterthur Swiss Insurance Company, he has overseen an entity active—and not just present—throughout the world. "We are a full-line insurer," he explains, and that means the Winterthur covers the territory from casualty to life to reinsurance. It operates through branches, subsidiaries, joint ventures and associated companies—and places great store in their smooth and effective coordination.

Non-Swiss business accounts for two-thirds of the firm's earnings. So it is hardly surprising that Winterthur—with about 12 billion Swiss francs of direct insurance booked, and a permanent staff of over 18,000 and thousands of agents—today finds itself positioned as one of the handful of European insurance companies likeliest to expand and prosper as regulatory walls tumble ever faster toward January 1, 1993.

Says Spälti: "I cannot speak about the strategy of our competitors, but what can be said—and this is the opinion of the outside experts who study us—is that there are six European insurance groups with a strong, well-established position, and the Winterthur is one of these. What does this mean? It means not only to be represented in one, two or three countries, nor to be represented in many countries with a small or merely symbolic presence. For us, it means to work in a substantial way in fifteen countries, and in some of these to be in the first ten in the marketplace." Taken together, all the countries in the world where Winterthur is active represent 90% of the world's insurance premium volume. "For instance, we are the fifth largest insurer in Spain among all companies, and the largest of the foreign ones. We are among the first ten in Italy, sixth in Belgium, the largest non-life insurer in France, strong in Portugal and medium-sized in Germany as in Denmark."

But then Winterthur started turning international early. Founded in 1875, within two years it had representations in half a dozen neighboring countries.

What is the Winterthur's plan in the United States? Is its strategy to grow by massive acquisition? Spälti: "Our approach is altogether different. We wanted to base our American business on regional, medium-sized companies because they have better results. And they are easier to control. Let me illustrate that: our recent acquisition, General Casualty (of Madison, Wisconsin), has had excellent results in the past and that will continue in the future. It always outperformed the industry by a wide margin. In the States, we find that the giant, national firms are often highly exposed in the casualty field, with large 'incurred-but-not-reported' losses, an unknown risk. That is much less an issue within our US companies."

Winterthur's latest acquisition in the US: General Casualty Insurance Companies.

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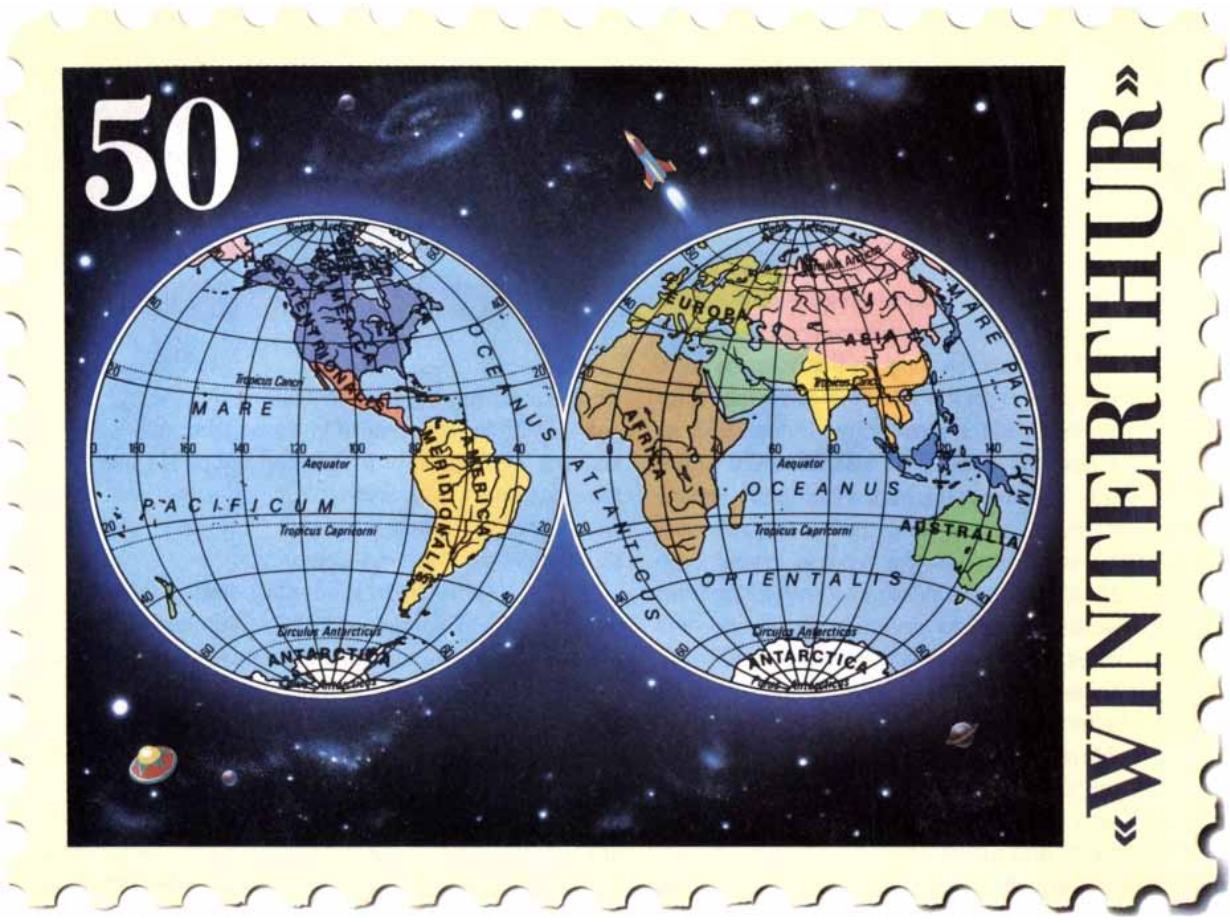

The ‹Winterthur› North American Network:

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Southern Guaranty Insurance Companies
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Republic Financial Services
Dallas, Texas

Winterthur Reinsurance Corporation
New York, New York

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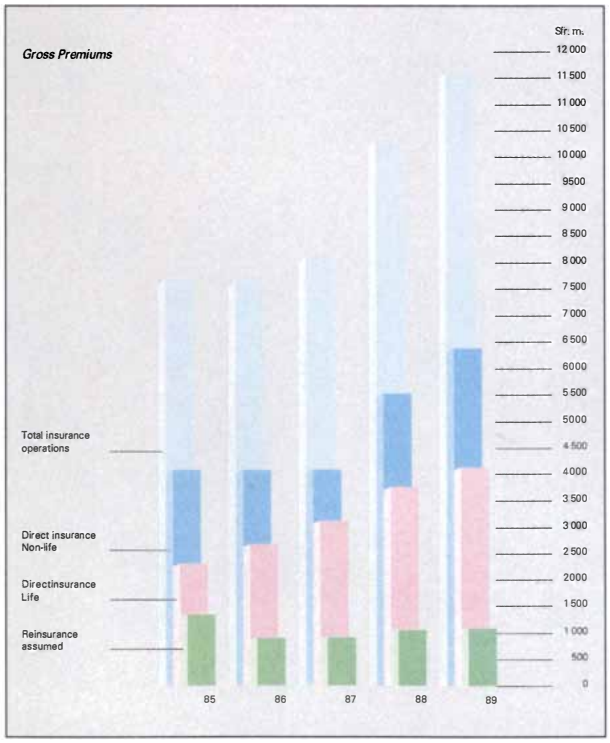
Headquarters of "Winterthur" Swiss Insurance Company.

In addition to the General Casualty, since 1982 Winterthur has owned Republic Financial Services in Dallas, mainly engaged in the combined household and fire insurance business, as well as in auto insurance. Southern Guaranty (headquartered in Montgomery, Alabama) also flies the Winterthur flag, which it is carrying throughout the Southeast.

Overall, in direct, primary insurance (not reinsurance) the US premium income of the Winterthur will be US $1.2-1.3 billion in 1990. Spälti: "For the moment, that seems sufficient. Our goal is not just to be as large as possible." The CEO is on record as saying the Winterthur will not become a financial services conglomerate "being everything to everybody".

Under direction of General Manager Hans-Rudolf Stucki, Winterthur's US operations (Winterthur Reinsurance Corporation of America, New York, is under the direction of the General Manager in charge of Reinsurance and the International Division at the Home Office) are pointed toward consolidation and expansion both. It is expected that the pay-back will prove more than satisfactory from the recent, major American purchases and they will soon weigh in to the sort of positive overall annual results which saw Group profits rise from 220.5 to 270.3 million Swiss francs from 1988 to 1989.

Gross premiums written by the Winterthur Group.

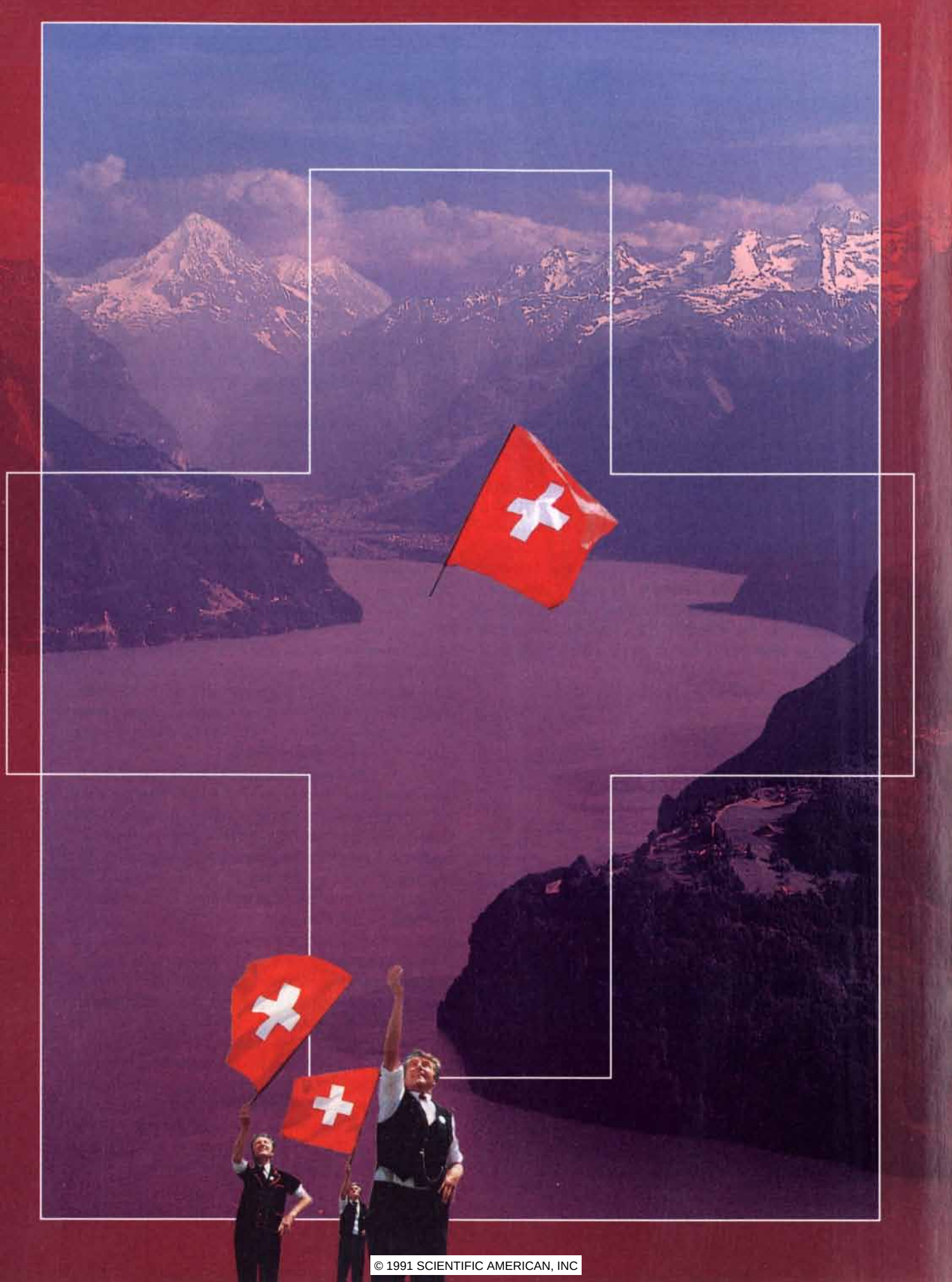


Both Spälti and Stucki relish the challenge of competing in US markets. The Chairman and CEO explains, "The American corporate manager seeking insurance should come to us because we are international in a way no US company is, for none of them can deliver a genuine international network and the experience of decades of working abroad, speaking foreign languages, understanding foreign markets and cultures. The US firms are giants in a giant market, only that."

Spälti has a particular vantage point on European unity, and the Swiss place in it. As politician, businessman and military officer, he is at once sanguine and secure: "In 1989, we founded Winterthur-Europe, in Brussels, which offers 'European policies' to corporate clients. We are already a real EC company, one of the ten world insurance players truly able to provide the services needed by multinational business."

But ought his country to seek full EC membership, lining up after neighboring Austria? Spälti admits that "in purely economic terms", Switzerland might do well to seek membership. "But there are also important questions of legal structure, neutrality, federalism, of history and of politics. I believe we cannot join as a full member in the medium timeframe since it would require changing so many aspects of life, notably in a direct democracy where people can challenge a law on all levels or present a proposal through organizing a public vote. I think the structure of our state and the values of our people would not 'digest' this change in the foreseeable future." He has said that Switzerland "...is more important to the EC as a partner than many a member state."

The proper path? "We should come nearer the EC step by step. The route is through the European Economic Space, and the question is what are the conditions for joining, something now in negotiation. For the Winterthur, strictly speaking, we are so well prepared abroad that it would not make much difference."



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SCIENTIFIC AMERICAN February 1991 Volume 264 Number 2

Sexually Transmitted Diseases in the AIDS Era

Gonorrhea, syphilis and other infections still exact a terrible toll. Social conditions help to fuel the new epidemics—and only a combination of social and health programs can defeat them

by Sevgi O. Aral and King K. Holmes

In almost all of the industrialized countries the three classic venereal diseases—gonorrhea, syphilis and chancroid—have nearly disappeared. Throughout Europe, Australia, New Zealand and Japan the incidence of gonorrhea has been declining steadily for 15 to 20 years. In Sweden alone the gonorrhea rate dropped by more than 95 percent between 1970 and 1989. These improvements probably reflect the effectiveness of public health measures taken in those countries.

In shocking contrast, those three sexually transmitted diseases (STDs) have actually been increasing at epidemic rates among urban minority populations in the U.S. Urban poverty and social disintegration, along with prostitution and the relatively new phenomenon of sex in exchange for drugs, seem to underlie this epidemic.

Further compounding the STD problem in the U.S. are the rise of drug-resistant strains of sexually transmitted bacterial infections and the rapid spread of incurable viral STDs. The deteriorating STD situation of the U.S. urban underclass increasingly resembles that seen in the slums of the least developed countries, where acquired immunodeficiency syndrome (AIDS), caused by the human immunodeficiency virus (HIV), has been spreading at epidemic rates among heterosexuals.

We have reviewed the available data on the incidence of STDs as well as on the social, economic and political forces that seem to be fueling the epidemic. Our conclusion is that certain policies must be implemented if the U.S. is to control STDs in general and to prevent a heterosexual HIV epidemic in the urban underclass.

Data on the incidence of gonorrhea and syphilis, which are perhaps the best known of the STDs, demonstrate the trends we have observed. Traditionally the reported incidence of gonorrhea in the U.S. has been higher among men than among women and higher among blacks than among whites. Since 1975 intensified public health efforts, along with the aging of the "baby boom" generation, have brought about a decline in the overall incidence of gonorrhea in the U.S.

Yet this reduction has not been consistent throughout the entire population. The racial difference in the gonorrhea rates has sharply widened since 1984, when the incidence among blacks began rising rapidly. (Some of the difference between the races may reflect underreporting of the disease in whites: whites more frequently rely on personal physicians and private clinics, which tend to report gonorrhea cases less thoroughly than do public clinics.)

Much has been learned about the spread of gonorrhea by studying antibiotic-resistant strains of gonococcal bacteria. Until 1976, all cases of gonorrhea could be cured by penicillin. In that year, however, a man traveling to the U.S. from the Philippines was found to have a resistant strain. Such strains began to spread globally, and by 1987 they accounted for 2 percent of all the cases reported in the U.S. That proportion reached 5 percent by 1989.

SEXUALLY TRANSMITTED viruses and bacteria are responsible for epidemics in the developing world and in certain U.S. populations. These micrographs show an isolated hepatitis B virus (*a*), herpes simplex virus type 2 (*yellow and green*) inside an infected cell (*b*), intracellular bacteria called *Chlamydia trachomatis* (*orange*) that cause chlamydial infection (*c*) and the human immunodeficiency virus (HIV) (*d*) that causes AIDS.

SEVGI O. ARAL and KING K. HOLMES are well known for their extensive epidemiological studies of sexually transmitted diseases. At the Centers for Disease Control in Atlanta, Aral is the behavioral studies section chief of the division of sexually transmitted diseases and HIV prevention in the Center for Prevention Services. She received her doctorate in social psychology from Emory University in 1972. Holmes is professor of medicine and director of the Center for AIDS and Sexually Transmitted Diseases at the University of Washington. He received his medical degree from the Cornell University Medical College in 1963 and his doctorate in microbiology from the University of Hawaii in 1967.

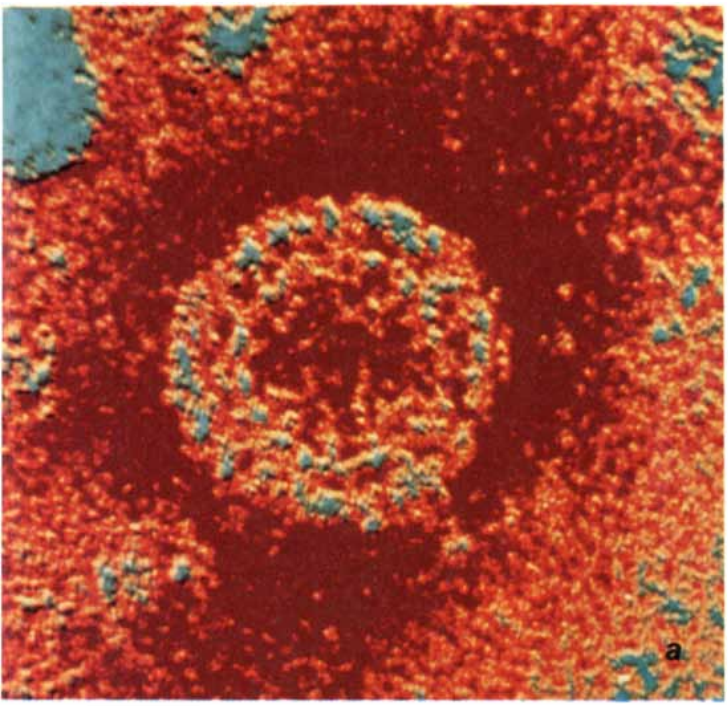
Because penicillin-resistant strains are easily identified, they can be traced as they move through a community. In Seattle during 1986 and 1987, for example, an outbreak of approximately 200 cases of gonorrhea was caused by a unique resistant strain. The first cases predominantly involved white and Hispanic men who often had a history of prostitute contact. After several months, however, nearly all the cases involved heterosexual black men and women, more than 80 percent of whom had histories of recent prostitution or sex with prostitutes or recent use of intravenous drugs or "crack" cocaine.

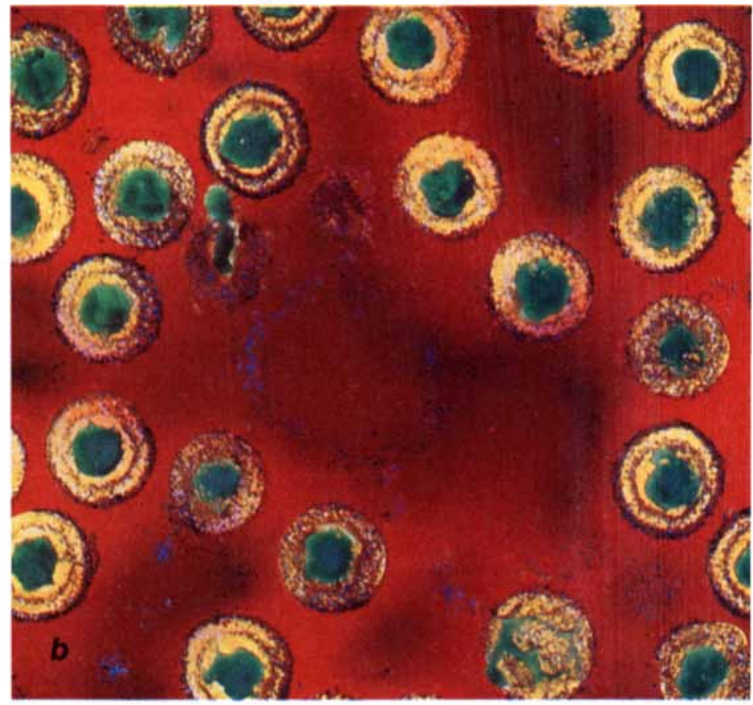
This patient profile was distinctly different from that of the 1960s and 1970s, when cases of gonorrhea in Seattle usually involved whites and were rarely linked to prostitution or illegal drug use. It heralded a national pattern that would also characterize the emerging epidemiology of other STDs such as syphilis.

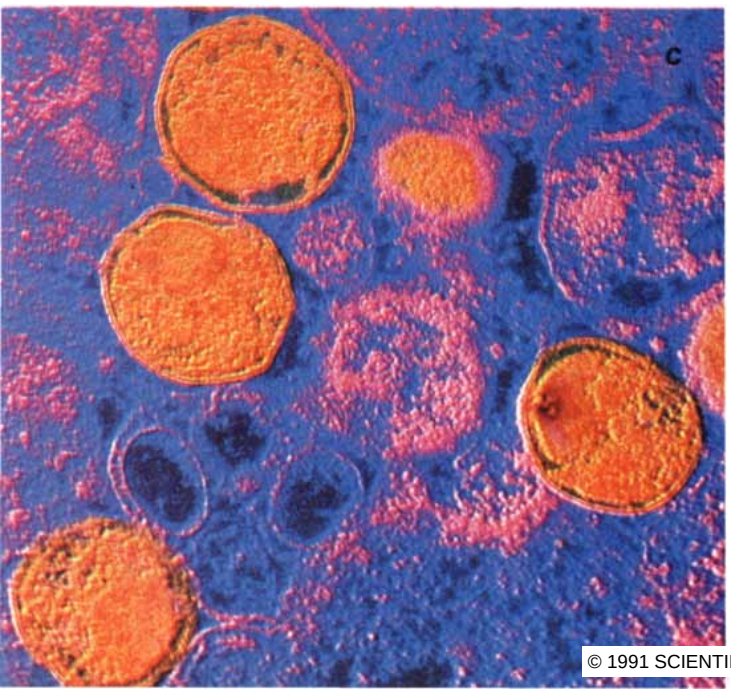
In the U.S. the incidence of infectious syphilis cases peaked at 76 cases per 100,000 citizens after World War II and then fell to only four per 100,000 citizens for 1955–1958. In 1959 the trend reversed, and the incidence rose rapidly to 12 per 100,000 in 1965—triple the level of just a decade earlier. The increase has often been attributed to a decline in federal funding for syphilis control.

Between 1965 and 1982 the total incidence of infectious syphilis changed very little in women but more than doubled in men because of an epidemic of syphilis among homosexual men. From 1982 through 1986 the reported national rate of infectious syphilis dropped steadily, largely because of a steep decline in the incidence among homosexual men, whereas the rates in women changed very little. Between the last quarter of 1986 and the end of 1989, however, the incidence rose sharply in men and women.

This overall increase is actually attributable to a very steep rise in infections among black men and women since 1985. The pattern of resurgent syphilis has been further documented in local syphilis outbreaks in New York





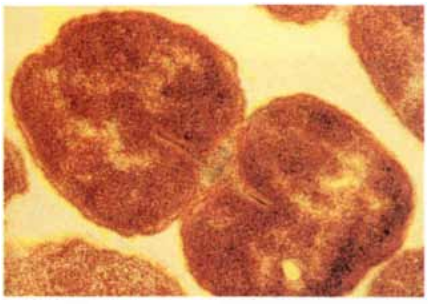


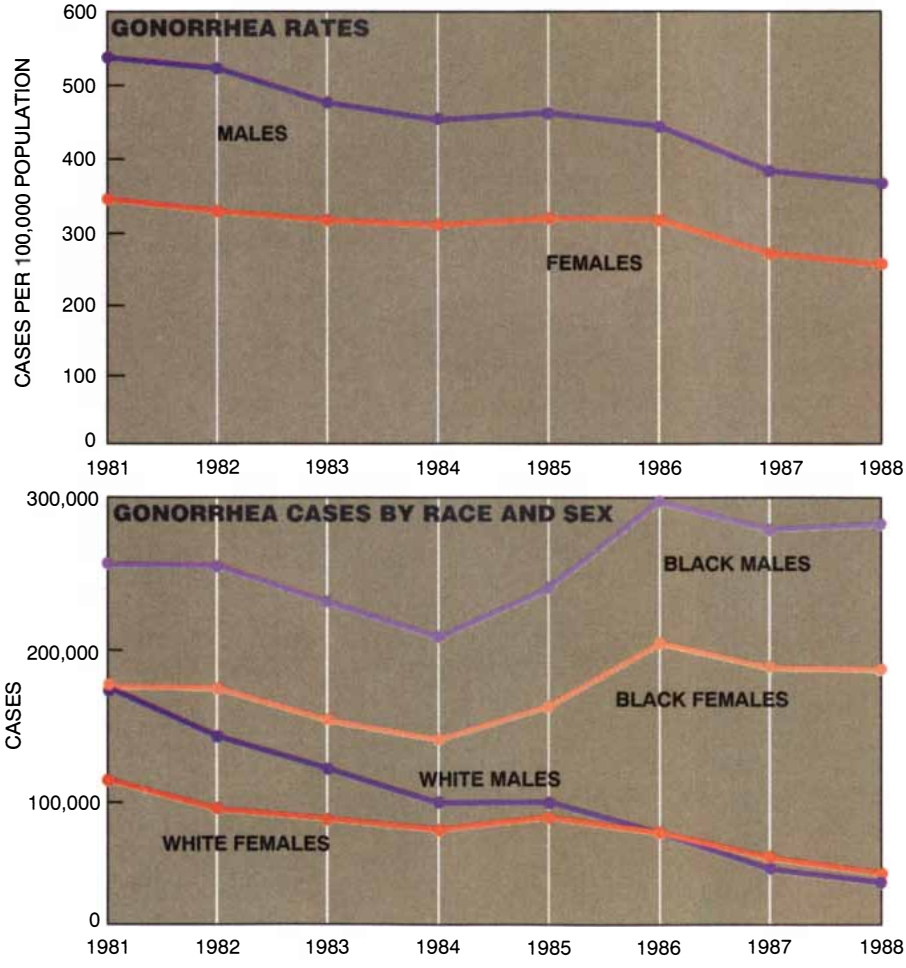
City, Philadelphia, Baltimore and Los Angeles and some areas in Texas and South Florida. In Philadelphia and New York, the use of crack cocaine and the exchange of sex for it have been closely linked to a higher incidence of syphilis.

The distribution of syphilis in the U.S. population is also reflected by blood test data collected in a national health and nutrition examination survey of the U.S. population (known as NHANES II) conducted between 1976 and 1980. Youth, single marital status, lack of education, low income and urban residence were all found to be associated with positive blood tests for syphilis, but the greatest difference was seen between races: controlling for other factors, the rate of positive blood tests was almost fivefold higher among blacks than among whites.

Another STD of growing importance in the U.S. is chancroid. In Africa this infection is the most common cause of genital sores, and it has always been strongly linked to prostitution and to sex with prostitutes. In 1985 a multinational research group found genital ulcers, most of which were chancroid, in 42 percent of the prostitutes from a slum area of Nairobi. Subsequent studies showed that genital ulcers in prostitutes and in male STD clinic patients were associated with a greatly increased risk of sexually acquired HIV infection.

In the U.S. chancroid had been rare since World War II. Beginning in 1984, however, a series of outbreaks began to appear in the inner-city and migrant-labor populations of Los Angeles, Dallas, Boston, New York City, New Orleans and several Florida cities. The total number of chancroid cases reported in the U.S. rose from 665 in 1984 to 4,714 in 1989.





GONORRHEA is caused by the bacterium *Neisseria gonorrhoeae* (*top*). In the U.S. the incidence of gonorrhea declined overall during the 1980s (*middle*). But the gap between the incidence among black and white men and women has widened (*bottom*).

This increase could have profound public health consequences because chancroid may facilitate HIV transmission. Worse still, the bacterium that causes chancroid has developed resistance to many antimicrobial drugs. In persons who have been exposed to HIV, chancroid often fails to respond to some therapies that are otherwise highly effective. Thus, HIV infection may help the spread of a bacterial STD that in turn helps to spread HIV.

A fourth bacterial infection—one caused by intracellular bacteria called chlamydia—has now become far more common than gonorrhea, syphilis or chancroid in the U.S. It is also a much more important cause of reproductive health problems in women. Like the gonococcus, chlamydia usually causes infection of the urethra in men and of the cervix in women. If the infection ascends into the uterus and fallopian tubes, it can cause abnormal bleeding, vaginal discharge or lower abdominal pain. Even in the absence of those symptoms, scarring of the fallopian tubes can cause blockages and sterility.

Because silent but destructive disease is the hallmark of chronic chlamydial infection, we feel screening for it should be part of routine pelvic examinations in women. Unlike gonorrhea, chlamydial infection commonly occurs in all racial and ethnic groups and in all socioeconomic classes. Young women and women using oral contraceptives seem more susceptible than others to acquiring chlamydial infection of the cervix if they are exposed.

Because laboratory testing for chlamydia is not yet widely used and chlamydial infection is not reported in most states, its incidence cannot be well documented. Still, it is clear that asymptomatic chlamydial infection is much more common in men and women than asymptomatic gonorrhea. It is common to find silent chlamydial infection of the cervix in up to 5 percent of middle-class pregnant women and female college students, whereas gonococcal infection is typically found in less than 1 percent. In two military studies, silent chlamydial infections of the urethra were found in about 10 percent of healthy, young men.

Chlamydial infection seems to be prevalent among the U.S. middle class because programs recommended for controlling the spread of chlamydia have not been widely implemented. Such programs have been very effective, at least in the middle class, at controlling gonorrhea, syphilis and chancroid. In Sweden and select areas of

the U.S., where public health measures for controlling chlamydia have been in place for several years, the number of infections has declined.

Comprehensive programs to control chlamydia have been formulated by experts at the national level but have rarely been implemented by local health departments and practicing physicians. In the U.S. the estimated direct medical costs and indirect costs associated with chlamydial infection came to $1.5 billion a year in the mid-1980s. Research has shown that chlamydial infection is the primary preventable cause of sterility in women and that the transfer of a mother's infection to her infant at birth can lead to a common form of infant pneumonia. A recently completed major multicenter study in the U.S. suggests that chlamydial infection in pregnant women is associated with premature birth.

Furthermore, chlamydial infection of the cervix causes inflammation resulting in microscopic cervical ulcerations. (This consequence is also probably true for gonococcal infection of the cervix.) Other STDs that cause obvious ulcerations of the genital skin seem to increase the risk of acquiring or transmitting HIV infection sexually. It is not surprising, then, that two studies in Africa have suggested that women with cervical chlamydial infection are at greater risk of acquiring HIV infections sexually.

In view of the overwhelming evidence that chlamydial infection is the most common curable STD and a major cause of infertility in women and that it increases the susceptibility of women to HIV, it is difficult to understand why many programs for STD control, family planning and maternal-child health do not provide diagnostic testing for this disease.

Unfortunately, not all STDs are caused by bacteria, and therefore not all are curable with antimicrobial agents. Viruses cause STDs as well, and these represent an especially difficult public health challenge because they cannot yet be cured. Lesions caused by the human papillomavirus can be eliminated or suppressed with toxic chemicals, freezing, electrocautery or laser therapy, but these procedures cannot rid a patient of the virus.

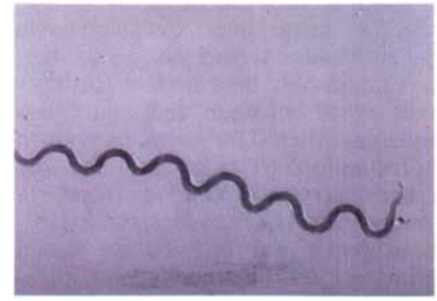
During the late 1970s and 1980s, new tests were developed that could detect the proteins and DNA of viruses that cause STDs. Epidemiological studies based on these tests are now disclosing the vast scope of the viral STD problem as well as the distribution and determinants of these infections.

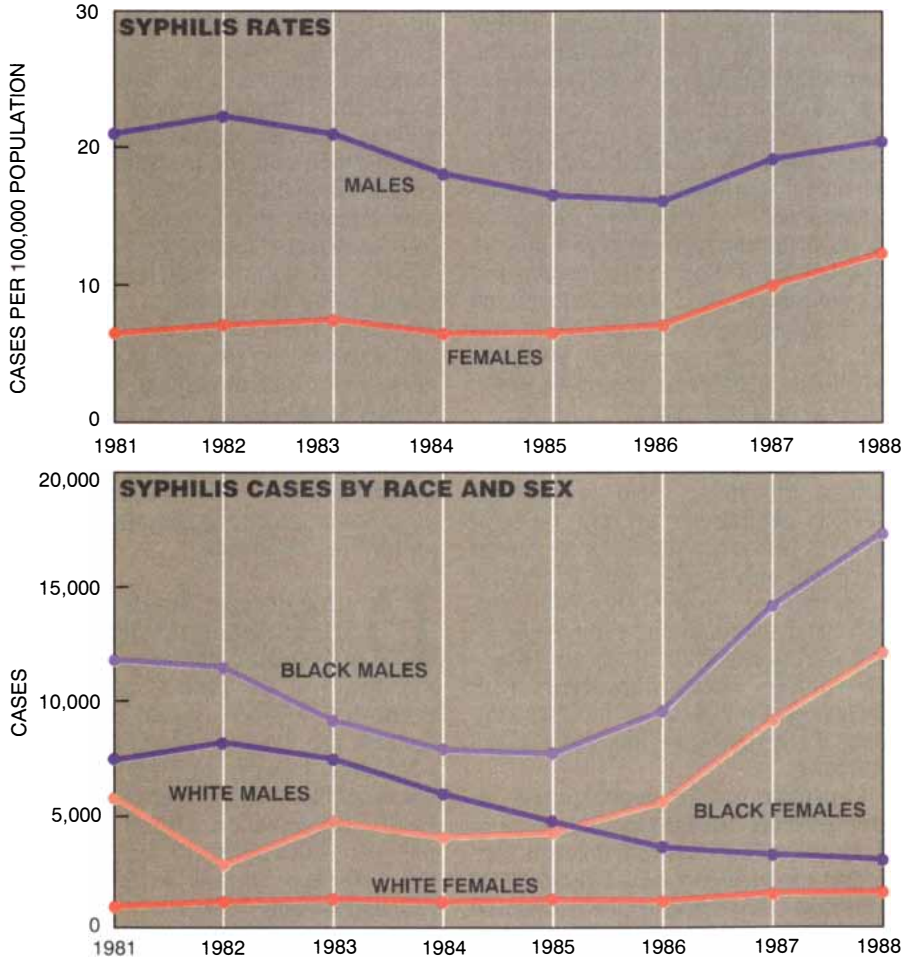
Genital herpes and genital warts, both of which are caused by viruses, seemed to be the most rapidly spreading STDs from the mid-1960s until the onset of the AIDS epidemic. The full extent of the problem was not clear, however, until random samples of blood serum collected during the late 1970s were tested for the presence of antibodies against herpes simplex virus type 2 (HSV-2). The presence of such antibodies almost always reflects previous genital infection with the virus.

The results suggested that approximately 25 million U.S. civilians had been infected with HSV-2 as of 1978—about 10 times more than might have been expected from the reported number of physician consultations for genital herpes. The data also showed that HSV-2 antibody is approximately two to three times more common among blacks than whites and that, at least among blacks, women are more likely to have HSV-2 antibodies than men. Antibodies to HSV-2 are more prevalent among persons of lower socioeconomic class and inner-city residents.

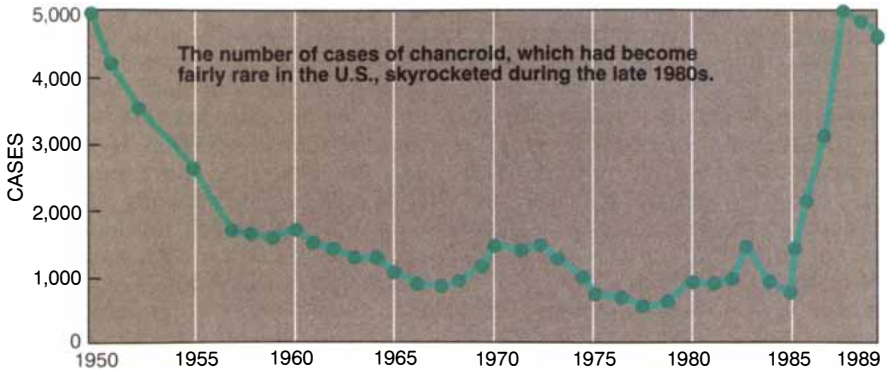
Two groups of researchers, one led by Andre Nahmias of Emory University, the other by Lawrence Corey of the University of Washington, found that only one quarter to one third of persons with serum antibody to HSV-2 were aware of having previously had symptoms consistent with genital herpes. Only a few genital HSV-2 infections ever seem to cause recognizable symptoms. New cases of genital herpes often arise after persons are exposed to the virus by a sex partner with an asymptomatic infection.

During the 1970s, researchers ob-





SYPHILIS is caused by the bacterium *Treponema pallidum* (*top*). The incidence of syphilis decreased among men during the early 1980s but later rose in both sexes (*middle*), primarily because of increases among black men and women (*bottom*).



served an association between cancer of the cervix and genital herpes. Many women infected with HSV-2 were counseled that they might be at serious risk for cervical cancer. Yet some medical authorities argued that genital herpes might only be a marker for high-risk sexual behaviors that could also transmit other STDs—perhaps even an unrecognized STD that was the true cause of cervical cancer. Many researchers therefore began to look more closely at genital warts, which are benign growths caused by the human papillomavirus (HPV).

A major advance in the study of HPV came with the application of recombinant DNA technology, which could isolate and clone, or copy, strands of DNA from papillomaviruses in warts. The cloned HPV-DNA could be labeled radioactively and used to probe for complementary DNA strands in genital lesions, including cancerous and precancerous lesions. Harold zur Hausen and his colleagues from West Germany led in identifying new types of HPV by this method. Today more than 60 types have been identified, several of which cause genital infections.

Like herpes infections, few of which produce sores, only a minority of HPV genital infections seem to produce obvious genital warts. Those types of HPV that most commonly cause genital warts are only rarely found in cervical cancer tissue. On the other hand, certain types that do not usually cause visible warts—especially types 16, 18 and 31—are very strongly associated with precancerous lesions or invasive cancers of the cervix, vagina, vulva, penis and anus.

Consultations for genital warts increased from 169,000 in 1966 to more than two million in 1988. It seems likely that the incidence of subclinical HPV infections, including those associated with genital cancers, is rising at a similar rate.

At the moment, genital and anal HPV infections appear to be the most prevalent STDs in the U.S., and a large proportion of sexually active adults seem to be infected. In a recent survey, HPV type 16 was detected in the Pap test specimens of 22 percent of female college students and 44 percent of female STD clinic patients in Seattle. The implications of finding a cancer-associated virus in such a high proportion of young women is obviously of great concern.

Hepatitis B infection is another important viral STD. There are an estimated 200 million carriers of hepatitis B virus in the world, and the number of new cases a year in the U.S. is estimated to be 300,000. It is discouraging to note that the overall measured incidence of hepatitis B has not declined much since 1982, despite a steep decline in high-risk homosexual contacts among men and the availability of an effective hepatitis B vaccine. Of all the new hepatitis B infections attributed to a known risk factor, the percent attributed to homosexual contacts declined from 21 percent in 1982 to 9 percent in 1987. During that same period, however, the proportions attributed to heterosexual contact and intravenous drug use both rose, from 15 to 22 percent and from 15 to 28 percent, respectively. Hepatitis B virus infection attributable to heterosexual contact is most common among persons of lower socioeconomic status.

During the past decade, the viral STD attracting the most attention from both the medical authorities and the general public has been AIDS, which is caused by HIV infection. On a global basis, the overwhelming majority of HIV infections are sexually transmitted. The World Health Organization projects that by the year 2000, up to 90 percent of all HIV infections in the world will be transmitted heterosexually.

Of the sexually transmitted HIV infections, most of those occurring in North America have been transmitted homosexually to men who practiced receptive anorectal intercourse, whereas most of those occurring in Africa and parts of the Caribbean have been transmitted heterosexually to women and men during vaginal intercourse. Heterosexual transmission also accounts for a growing proportion of the cases of AIDS and HIV infection in Europe and Latin America, and heterosexual HIV infections are now proliferating at explosive rates in parts of Thailand and India. Homosexual transmission predominates among men in North America, but heterosexual transmission is increasing: it accounted for approximately 5 percent of the newly diagnosed cases of AIDS in the U.S. in 1988 and 1989, including nearly 30 percent of the cases in adult women.

In the U.S., cases of AIDS ascribed to heterosexual transmission have disproportionately involved urban minority populations. For example, among U.S. men the incidence of heterosexually acquired AIDS is approximately 10 times greater for blacks and four times greater for Hispanics than for whites. There are several possible explanations for this pattern. The incidence of HIV infection transmitted by intravenous drug abuse is higher among blacks and Hispanics, providing a reservoir for heterosexual transmission. The incidence of other STDs is also higher among blacks and Hispanics. To the extent that certain STDs are risk factors for sexual transmission of HIV, the higher incidence of such STDs in racial minorities also may contribute to the higher incidence of HIV in these groups.

The evidence that other STDs increase the sexual transmission of HIV can be summarized as follows. The STDs that cause genital ulcer disease—chancroid, syphilis and genital herpes—have been associated with an increased risk of acquiring HIV infection in heterosexual men and women in Africa. Syphilis and herpes have also been associated with HIV infection in heterosexual men and women and in homosexual men in the U.S. In African women the risk of heterosexual acquisition of HIV has been elevated in those with gonorrhea or chlamydial infection of the cervix or those with a form of vaginal discharge caused by *Trichomonas,* a common parasite.

Conversely, HIV infection leads to altered manifestations of other STDs and thereby probably promotes their spread. Genital and anorectal herpes ulcers normally heal within one to three weeks, but they may persist for months as highly infectious ulcers in persons with HIV infection. As previously noted, HIV infection also raises the risk of treatment failure for chancroid ulcers. There is anecdotal evidence for the fail-

ure of syphilis treatments and for altered manifestations of syphilis and gonorrhea in HIV-positive persons. We can therefore postulate that HIV and other STDs may promote one another's spread. That vicious circle can best be interrupted by more aggressive control of STDs other than HIV.

STDs and AIDS constitute exceptions to the shifting disease patterns in the modern world. Economic development has been marked by a demographic transition: declining fertility rates and mortality (especially childhood mortality) change the age distribution of the population. The rising average age of the population creates what has been termed the epidemiologic transition, in which the infectious diseases of childhood become less important and the chronic diseases of adulthood become more important.

An extremely important consequence of these demographic and epidemiologic transitions has received little attention, however. When childhood mortality falls but birthrates do not, a huge increase in the number of teenagers and young adults precedes the increase in the number of adults. This trend can be pictured as a slowly ascending bulge in the age pyramid. Because sexually transmitted infections are concentrated among adolescents and young adults, these infectious diseases can be expected to rise in incidence as the population bulge passes through the teen and young adult years.

When the number of young people is disproportionately large, they may also be less influenced by the social norms of the older generation. Consequently, more of them may engage in behaviors that raise their STD risks. It is quite likely that the demographic shift has played a part in the epidemic of STDs and the increases in other phenomena of adolescence such as juvenile drug use and related crime.

Today the black and Hispanic populations of the U.S. have age pyramids that closely resemble those of developing countries, with large proportions of teens and young adults and relatively few older adults. The proportions of the younger age groups in the white population, meanwhile, are declining.

Furthermore, the poor inner-city minority populations of the industrialized countries (particularly the U.S.) resemble the populations of developing countries (particularly in their urban areas) in many other demographic, sociopolitical and economic characteristics that are conducive to the high incidence and rapid spread of STDs. First, both underdeveloped countries and inner-city minority populations are characterized by rapid demographic changes. Developing countries generally have high population growth rates, high rates of urbanization and population movements of all types. Inner-city populations in the industrialized countries, too, are highly mobile and change rapidly through middle-class flight and the increasing concentration of young, poor minority populations.

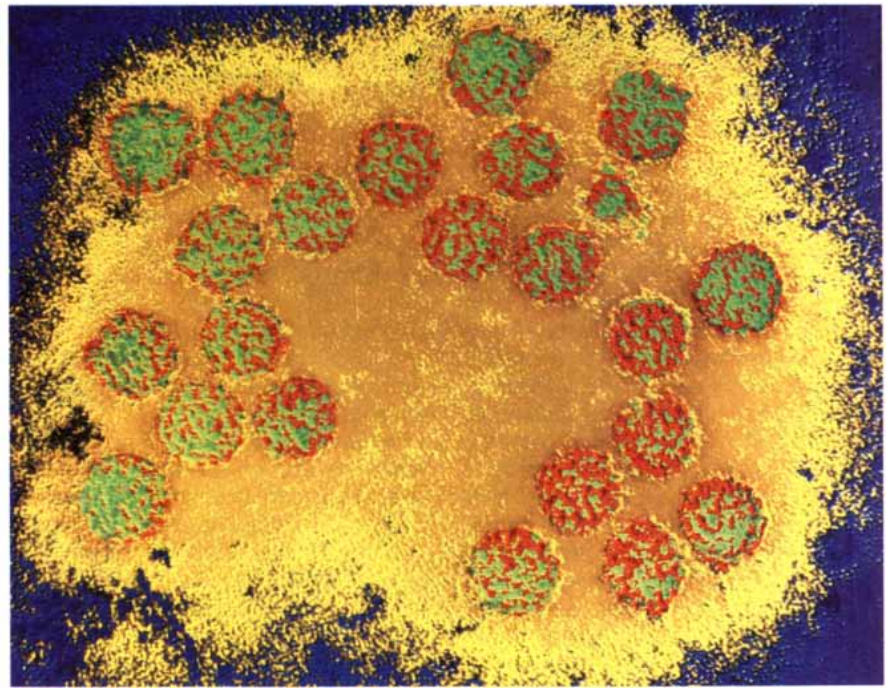
Rapid, drastic economic changes also mark both developing countries and industrialized inner cities. Developing countries fundamentally restructure themselves as they make the transition from agricultural self-sufficiency to dependence on wage labor. Similarly wrenching changes occur in some U.S. inner-city minority communities because of the sale of drugs, especially crack cocaine. Large sums of money change hands very quickly in the drug trade: this money is introduced suddenly into the daily life of inner-city communities, often through very young teenagers, thus radically altering the social structure.

Underdeveloped countries and inner-city minority populations both have unstable power hierarchies. In many parts of the Third World, frequent civil wars, coups and border disturbances and the need for a strong police and military presence to assure peace in daily life testify to the lack of political stability. Similarly frequent violence in the inner cities of the U.S. points to the tentative nature of power hierarchies in those communities.

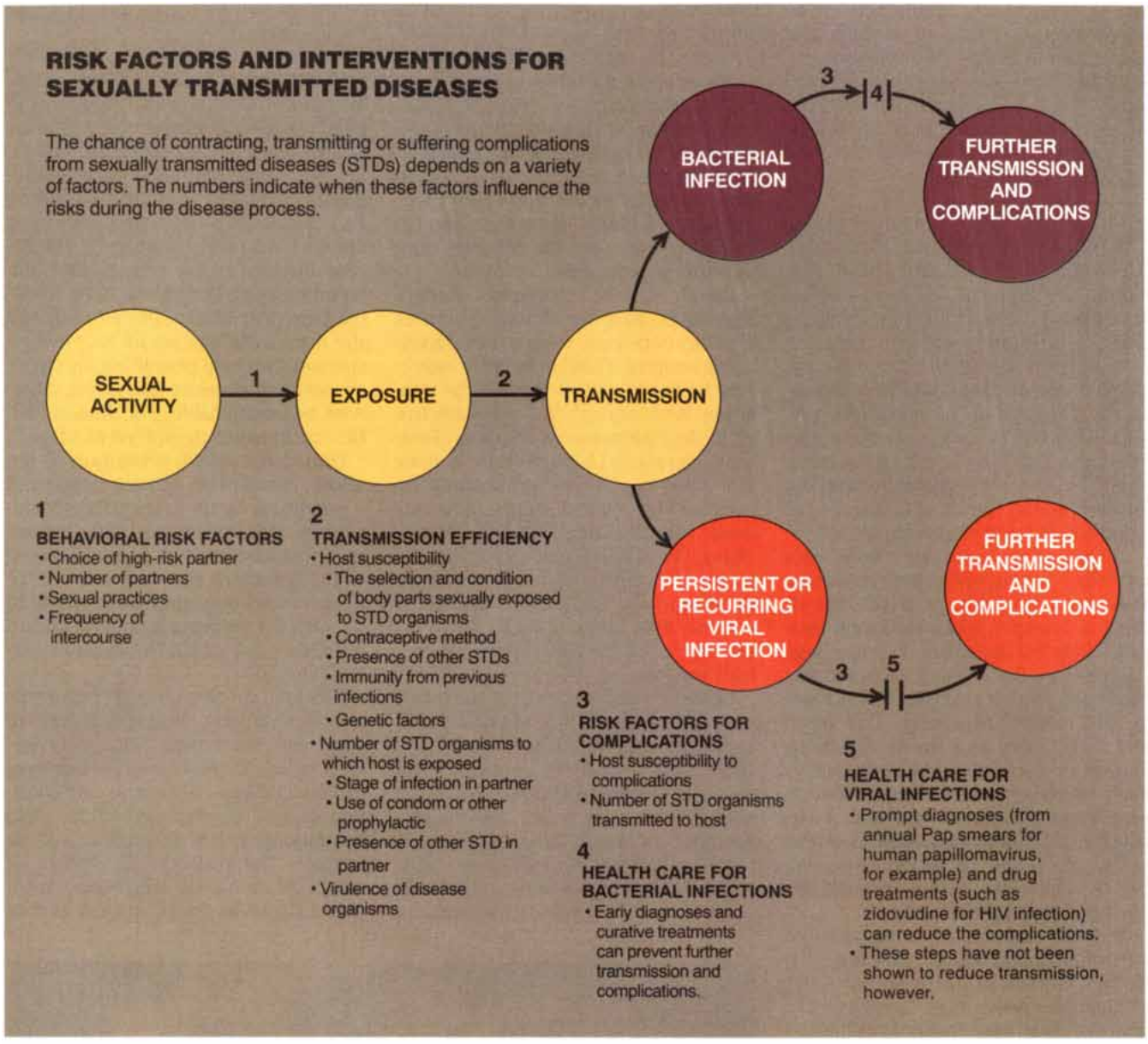
The swift demographic, economic and political changes in these populations result in a social situation in which levels of transience and marginality are high. These conditions reinforce exchanges based on socioeconomic inequality, such as prostitution and illegal drug use. Prostitution has always been most common in settings characterized by poverty, social disintegration and a double standard of sexual behavior. Indeed, prostitution and the drug trade emerge as adaptive responses that help people acquire money, power or pleasure that would otherwise be unattainable. Yet those activities can enhance the spread of STDs.

During the sexual revolution of the 1960s, prostitution was not considered a prominent factor in the STD epidemic in the U.S. During the 1980s, however, prostitute contact has reemerged as an important risk factor for STDs. Its increased importance has partly to do with the growing tendency toward transiency among the U.S. inner-city urban population.

The men involved in STD outbreaks are often (but not always) transients of some kind: foreigners, military servicemen, truck drivers, migrant laborers and so on. Their only sexual, and sometimes social, interactions with the main community may be through prostitute contact. The male-specific nature of most international migration (most markedly in its initial stages) and of



HUMAN PAPILLOMAVIRUSES cause the benign growths called genital warts. Some types that do not usually cause warts are associated with a variety of cancers.



most temporary unskilled and semiskilled labor tends to reinforce and foster prostitute contact.

Recent studies in urban areas of the U.S. have also found that transmission of gonorrhea, syphilis, chancroid and HIV infections has been closely associated with the exchange of sex for drugs such as crack. Women, particularly adolescent women, sometimes engage in very large numbers of sexual contacts to support their addiction. The epidemic increase in crack cocaine use, which began in the U.S. around 1985, therefore seems to be a major contributor to the simultaneous epidemic increase in syphilis, chancroid and gonorrhea among inner-city minority groups.

What can be done to interrupt the self-reinforcing relationships between STDs, AIDS and social problems such as prostitution and drug abuse? Sexual and health care behaviors both strongly determine the incidence of bacterial STDs and their complications. Sexual behaviors influence the spread of the diseases, and good health care behaviors—which lead to prompt medical consultation and notification of exposed sex partners—result in curative treatments and the interruption of the chain of transmission.

For the spread of viral STDs, sexual behaviors are much more important than health care behaviors because the diseases are not curable. Still, health care can be important for individuals: regular Pap tests enable early detection of precancerous conditions in the cervix, and early detection of HIV infection now leads to life-prolonging medical interventions.

Efforts to change individual and societal behavior may seem impotent in the face of the trends we have discussed. Yet the evidence of changing sexual behaviors among homosexual men and the increasing use of condoms by customers of prostitutes in many societies stand as testimony to the power of public health efforts.

The steady decrease in the incidence of gonorrhea and syphilis among adult white heterosexuals in the U.S. and other countries is consistent with the institution of effective public health control measures. Yet the reemergence of bacterial STDs in young, black and Hispanic inner-city poor populations, coupled with the rising incidence of AIDS and other viral STDs, has created a demand for public health care and preventive interventions that exceeds the capacity of many systems to provide diagnostic and treatment services.

As bacterial STDs in industrialized

countries concentrate within specific high-risk heterosexual populations and population subgroups—the so-called core groups of frequent transmitters for these diseases—innovative programs are needed to focus STD control efforts. Core groups can be defined as those in which the rate of transmission is high enough to sustain an STD within the population: on average, every infected person infects at least one other person. Preventing or curing an STD in a member of a core group has much more impact than doing so in a person who is unlikely to transmit the infection.

A public health focus on the determinants of STDs in individual cases and prevention approaches that identify persons most at risk are most appropriate when exposure to the cause of a disease is heterogeneous in the population. Yet as Geoffrey Rose of the London School of Hygiene and Tropical Medicine asserted in a paper in 1985, the population approach becomes more important as a group's exposure to a disease becomes more homogeneous and widespread. Therefore, choosing the most appropriate disease-control strategy depends on determining the relative heterogeneity of exposure to causal factors within and across population subgroups.

At present, U.S. society is marked by increasing homogeneity within social groups and a widening gap between them. The formation of a growing underclass reflects these tendencies. Such social problems as lack of education, joblessness, homelessness, welfare dependency, family dissolution, drug abuse, homicide and other crimes concentrate more and more in inner-city neighborhoods.

STDs and many other health problems also follow this pattern. The incidence rates and morbidity for many STDs differ greatly among socioeconomic, demographic and behavioral subgroups. Within these subgroups, the risk factors that determine what causes individual cases of STDs may be far less important than the overriding social forces.

Consequently, the strategies for preventing STDs should target not only susceptible high-risk persons but also entire communities and subgroups with high STD rates. Such strategies, ranging from improved birth-control services to better educational and job opportunities, should address the full scope of factors underlying the high rates.

During the 1980s, public STD services in the U.S. were overwhelmed and inadequately supported. The demand for public health care has exceeded the capacity to provide diagnosis and treatment. STD clinics are closing earlier in the day, patients are waiting longer hours to receive care and greater numbers of people are being turned away without receiving care. Although people are invited to return the next day or after the weekend, the close association of STD with drug use and with sex for drugs ensures that many potential patients will continue to spread infection after being turned away.

In a survey we conducted in May 1989, 19 out of 23 public STD clinics throughout the U.S. reported one or more features of the pattern of delayed treatment. It is ironic that public health officials lament the difficulty of finding the sex partners of crack-using patients with STDs and emphasize the need for more workers to trace sexual contacts, while people who do show up at the clinics are being turned away because of a lack of services.

Clinical services for diagnosing and treating STDs must be greatly expanded until all patients can be examined and treated on the day that they present themselves. That goal will require expanded clinic facilities, recruitment of trained clinicians and substantially increased funding for diagnostic testing of STDs, especially chlamydial infections. STD services also can be increased by closer integration with programs for family planning, prenatal care and AIDS prevention. In this way, persons who seek such care can also receive routine screening and treatment for STDs. Family-planning services should also be available through STD clinics, but that step will require even further expansions of clinical staffing.

Control of STDs in the inner-city underclass also calls for new approaches, such as satellite clinics in inner-city neighborhoods, that reach out to the affected communities. Mobile clinics or vans could provide services to the growing homeless population. In addition, innovative behavioral interventions must be expanded to prevent the incurable STDs. Health care education and other interventions must be offered in terms that are appropriate but explicit to youths in and out of schools in the communities at risk. It is essential that the inner-city communities and the health sector work as partners in developing and administering the clinical services and behavioral intervention programs.

Because diverse health problems often overlap many social and economic problems, public health policies should be coordinated with other programs active in the community, such as Job Corps and Head Start. Low-cost housing and drug treatment and public service and prison programs could also be used to forge health initiatives. It seems that local governments serving the urban poor are no longer able to provide the levels of support essential for STD control services. Leadership and expanded support from national and state levels are needed.

Innovative approaches are needed to increase the availability of health care workers, particularly physicians, and services for urban poor populations. For instance, National Health Service Corps physicians could be deployed to treat AIDS and STDs among the urban poor. Without such help, it is unlikely that there will ever be enough physicians and nurses in the inner cities to meet the desperate need for services.

In the 1990s the solution to the STD crisis cannot rest solely on preventing high-risk behaviors in individuals. The factors that determine the high incidence of AIDS and other STDs in specific groups and in entire communities must also be identified and addressed. A balanced public health STD program for our cities in the AIDS era must include expanded clinical and health education services. Clinical services for STD control should grow to meet the demand, integrate with family-planning and related programs, and adopt the technological advances of the past decades in STD prevention and control. Prevention activities ought to include population and group approaches as well as individual counseling. By themselves, the medical solutions to the prevention and control of STDs and AIDS are not enough: they must be coupled with the identification and correction of the societal factors responsible for the global pandemic.

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The Number of Families of Matter

How experiments at CERN and SLAC, using electron-positron collisions, showed that there are only three families of fundamental particles in the universe

by Gary J. Feldman and Jack Steinberger

The universe around us consists of three fundamental particles. They are the "up" quark, the "down" quark and the electron. Stars, planets, molecules, atoms—and indeed, ourselves—are built from amalgamations of these three entities. They, together with the neutral and possibly massless partner of the electron, the electron neutrino, constitute the first family of matter.

Nature, however, is not so simple. It provides two other families that are like the first in every respect except in their mass. Why did nature happen to provide three replications of the same pattern of matter? We do not know. Our theories as yet give no indication. Could there be more than three families? Recent experiments have led to the conclusion that there are not.

GARY J. FELDMAN and JACK STEINBERGER were leaders in the effort to determine experimentally the number of families of matter. Feldman received his doctorate from Harvard University in 1971 and spent the following 19 years studying electron-positron annihilation at the Stanford Linear Accelerator Center (SLAC). He was co-leader of the Mark II, the experimental facility of the Stanford Linear Collider (SLC). Last fall he moved to Harvard and began studying proton-antiproton collisions at the Fermilab National Accelerator Laboratory in Batavia, Ill. Steinberger was born in Germany, came to the U.S. as a child and received his doctorate from the University of Chicago in 1948. Since 1968 he has been associated with the European laboratory for particle physics (CERN) near Geneva. Between 1983 and 1990 he headed Aleph, one of four experiments installed at the organization's Large Electron-Positron (LEP) Collider. He shared the 1988 Nobel Prize in Physics for his discovery of the muon neutrino in 1962.

In the spring and summer of 1989, experiments were performed by teams of physicists working at the Stanford Linear Accelerator Center (SLAC) and the European laboratory for particle physics (CERN) near Geneva. The teams used machines of differing designs to cause electrons (e^-) and positrons (e^+) to collide and thus produce quantities of the Z particle (or Z^0, pronounced "zee zero" or "zee naught").

The most massive elementary particle observed, the Z weighs about 100 times as much as a proton and nearly as much as an atom of silver. As we shall see, this mass is merely an average. The Z lifetime is so short that individual Z particles differ slightly in their mass. The spread in the mass values is called a mass width, a quantity that depends on the number of families of matter. Because this width can be measured experimentally, the number of families of matter can be inferred. In this article we describe the experiments by which the families of matter were numbered.

But let us first put this achievement into perspective. The past two and a half decades have witnessed a remarkable systematization of our knowledge of the elementary particles and their interactions with one another. The known particles can be classified either as fermions or as gauge bosons. Fermions are particles of spin 1/2, that is, they have an intrinsic angular momentum of $1/2\hbar$, where $\hbar$ is the Planck unit of action, 10^{-27} erg-second. Fermions may be thought of as the constituents of matter. Gauge bosons are particles of spin 1, or angular momentum $1\hbar$. They can be visualized as the mediators of the forces between the fermions. In addition to their spins, these particles are characterized by their masses and by their various couplings with one another, such as electric charges.

All known couplings, or interactions, can be classified into three types: electromagnetic, weak and strong. (A fourth interaction, gravity, is negligible at the level of elementary particles, so it need not be considered here.) Although the three interactions appear to be different, their mathematical formulation is quite similar. They are all described by theories in which fermions interact by exchanging gauge bosons.

The electromagnetic interaction, as seen in the binding of electrons and nuclei to form atoms, is mediated by the exchange of photons—the electromagnetic gauge bosons. The weak interaction is mediated by the heavy W^+, W^- and Z bosons, whereas the strong interaction is mediated by the eight massless "gluons." The proton, for instance, is composed of three fermion quarks that are bound together by the exchange of gluons.

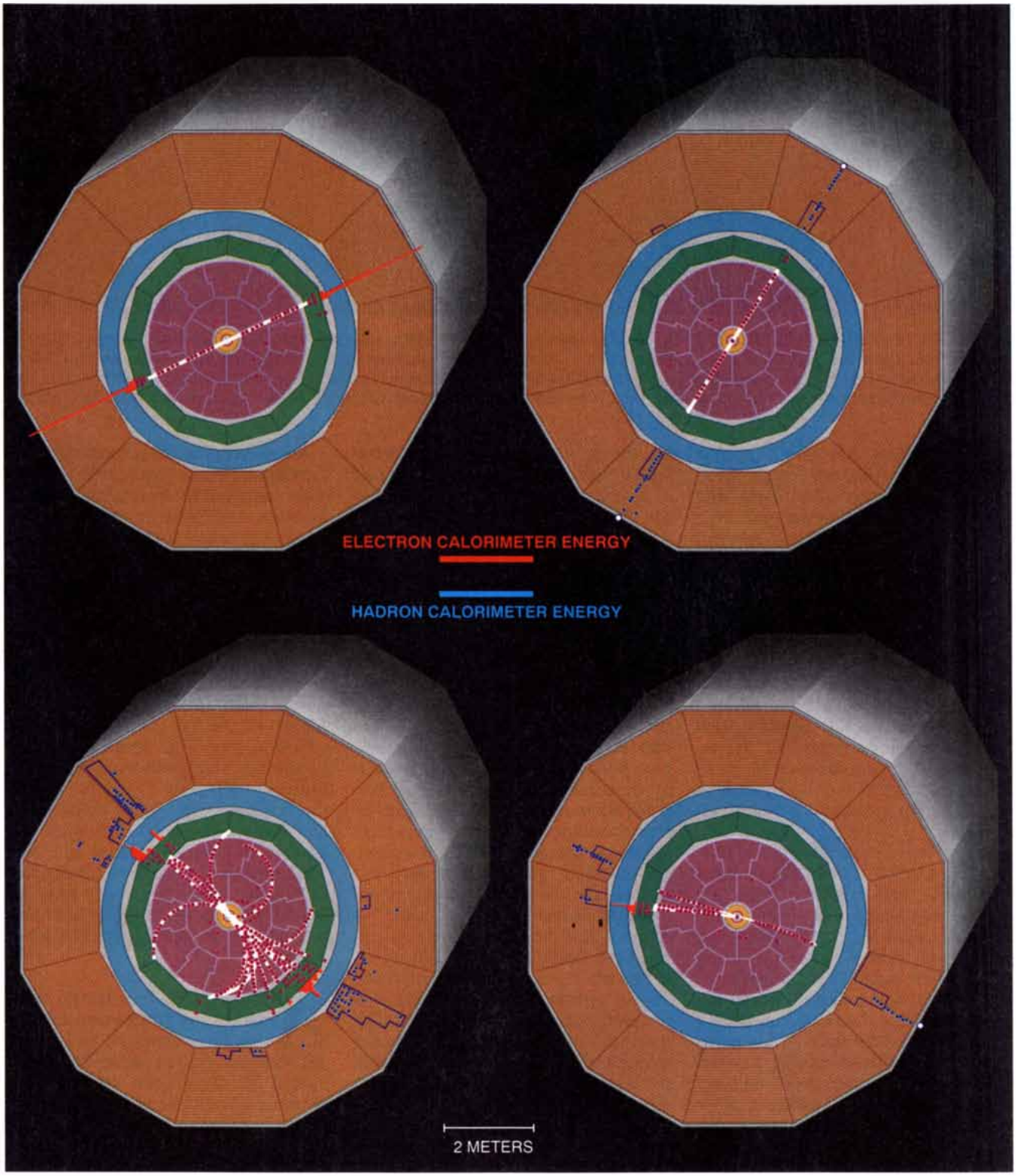
These interactions also describe the creation of particles in high-energy collisions. The conversion of a photon into an electron and a positron serves

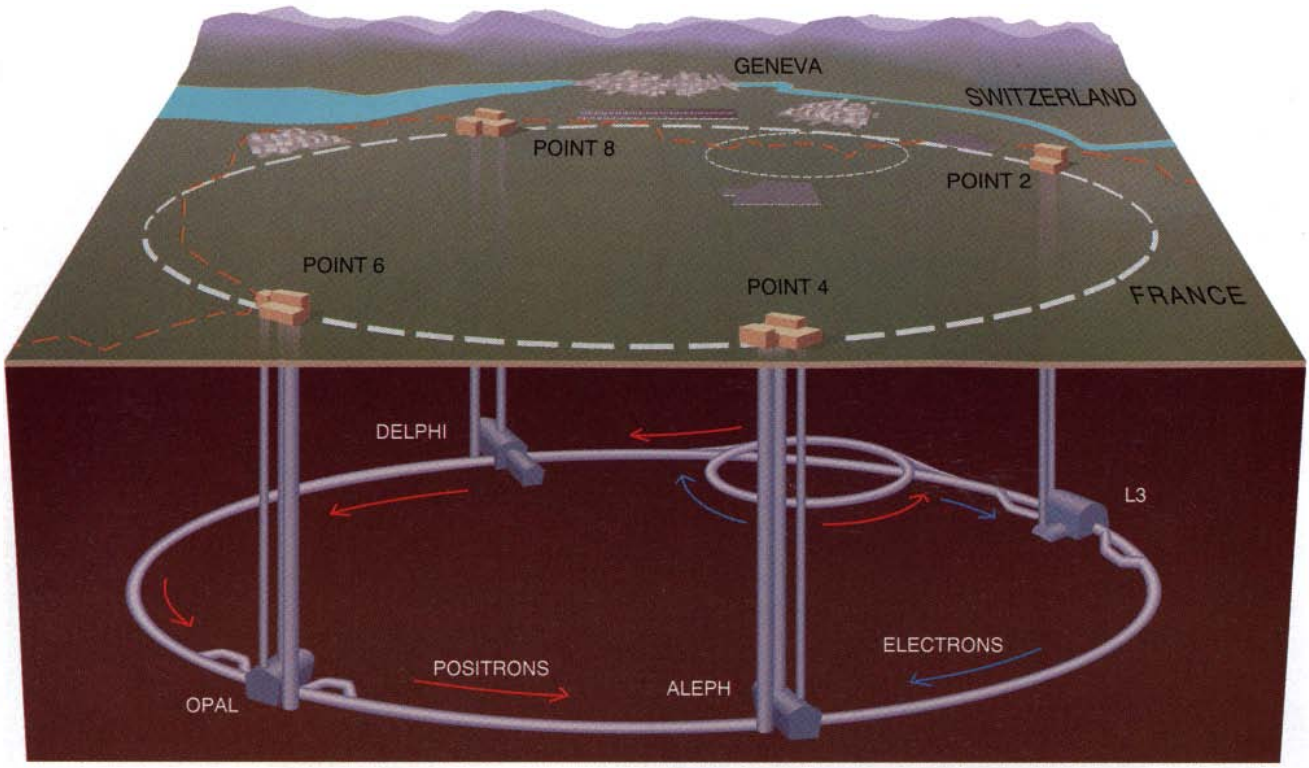
ALEPH DETECTOR, one of four at the Large Electron-Positron (LEP) Collider at CERN near Geneva, recorded these typical decays of *Z* particles. The cross-sectional diagrams show *Z* decay products as they traverse the detector. The four decays are (*clockwise, from upper left*) an electron and a positron, which appear as a single line of dots; two muons, which match the electrons' paths but penetrate the outer tracking devices; two tau leptons, one of which has decayed into a muon and two unseen neutrinos, accompanied by another that has decayed into three pions; and two quarks, which form hadron jets. Most *Z*s decay to quarks. Histograms (*blue and red*) represent particle energies.

as an example. So does the annihilation of an electron colliding with a positron at immensely high energy to produce a Z particle.

The evolution of these gauge theories constitutes a strikingly beautiful advance in particle physics. The unification of electromagnetism with the weak interaction was put forward during the years 1968–1971. This "electroweak" theory predicted the neutral weak interaction, discovered at CERN in 1973, and the heavy intermediate bosons W^+, W^- and Z^0, discovered 10 years later, also at CERN [see "Unified Theories of Elementary-Particle Interaction," by Steven Weinberg; SCIENTIFIC AMERICAN, July 1974].

The gauge theory of the strong interaction was advanced in the early 1970s. This theory is called quantum chromodynamics because it explains the strong force by which quarks interact on the basis of their "color." Despite its name, color is an invisible trait. It is to the strong interaction what charge is to the electrical one: a quantity that characterizes the force. But whereas electrodynamic charge has only one state—positive or negative—the color charge has three. Quarks come in red, green and blue; antiquarks come in antired, antigreen and antiblue.





LARGE ELECTRON-POSITRON COLLIDER creates *Z* bosons by bringing electrons and positrons into collision in a storage ring 27 kilometers in circumference. The particles countercirculate in bunches. Magnets confine the two beams to their proper orbits, and radio-frequency power accelerates them to a combined energy near 90 billion electron volts, equivalent to the *Z* mass. The bunches meet head-on 45,000 times a second at points inside the Aleph, Opal, Delphi and L3 detectors.

Together these two gauge theories predict, often with quite high precision, all elementary phenomena that have so far been observed. But their apparent comprehensiveness does not mean that the model is complete and that we can all go home. Gauge theory predicts the existence of the so-called Higgs particle, which is supposed to explain the origin of particle mass. No physicist can be happy until it is spotted or a substitute for it is supplied. Gauge theory also includes a number of arbitrary physical constants, such as the coupling strengths of the interactions and the masses of the particles. A complete theory would explain why these particular values are found in nature.

Among the rules the electroweak theory does provide is one that requires fermions to come in pairs. The electron and electron neutrino are such a pair; they are called leptons because they are relatively light. Another rule is that each particle must have its antiparticle—against the electron is posed the positron; against the electron neutrino, the electron antineutrino. When particles and antiparticles collide, they can annihilate one another, producing secondary particles. Such reactions, as we shall see, underlie the experiments discussed here.

To avoid some subtle disasters in the theory, it is necessary to associate with a lepton pair a corresponding pair of quarks. The electron is the lightest charged lepton, and therefore it is associated with the lightest quarks, the *u* quark (or up quark) and the *d* quark (or down quark). Quarks have not been seen in the free state; they are only found bound to other quarks and antiquarks.

The proton, for example, is composed of two *u* quarks and a *d* quark, whereas the neutron is composed of two *d* quarks and a *u* quark. A complete second family and most of a third have been shown to exist in high-energy experiments. In each case, the particles are much more massive than the corresponding members of the preceding family (the neutrinos form a possible exception). The second family's two leptons are the muon and the muon neutrino; its quarks are the "charm," or *c*, quark, and the "strange," or *s*, quark. The third family's confirmed members are its two leptons—the tau lepton and the tau neutrino—and the "bottom," or *b*, quark. The remaining quark, called the "top," or *t*, quark, is crucial to the electroweak theory. The particle has not been discovered, but we and most other physicists believe it exists and presume it is simply too massive to be brought into existence by today's particle accelerators.

No members of the second and third families are stable (again, with the possible exception of the neutrinos). Their lifetimes range between a millionth and a ten-trillionth of a second, at the end of which they decay into particles of lower mass.

There are two substantial gaps in the electroweak theory's grouping of particles. First, although the theory requires that fermions come in pairs, it does not specify how many pairs constitute a family. There is no reason why each family should not have, in addition to its leptons and quarks, particles of another, still unobserved type. This possibility interests a great number of our colleagues, but so far no new particles have been observed. Second, the theory says nothing about the central question of this article: the number of families of matter. Might there be higher families made up of particles too massive for existing accelerators to produce?

At present, physicists can do nothing but insert observed masses into theories on an ad hoc basis. Some pattern can, however, be discerned [*see illustration on page 73*]. Within a given class of particle (say, a charged lepton or a quark of charge +2/3 or of −1/3), the mass increases considerably in each succeeding family.

The smallest such increase is the nearly 17-fold jump from the muon in the second family to the tau lepton in the third.

Another striking feature is found within families. Leptons are always less massive than quarks, and in every pair of leptons the neutrino is always substantially the less massive particle. In fact, it is uncertain whether neutrinos have any masses at all: experimental evidence merely puts upper limits on the mass each variety can have.

This lightness of neutrinos is essential to the method reported here for counting the number of families of particles. Even if the quark and lepton members of a fourth, fifth or sixth family were far too massive to be created by existing accelerators, the likelihood is nonetheless great that their neutrinos would have little or no mass. Almost certainly the mass of such neutrinos would be less than half the mass of the Z boson. If such neutrinos exist, therefore, they would be expected to be among the decay products of the Z, the only particle that decays copiously into pairs of neutrinos.

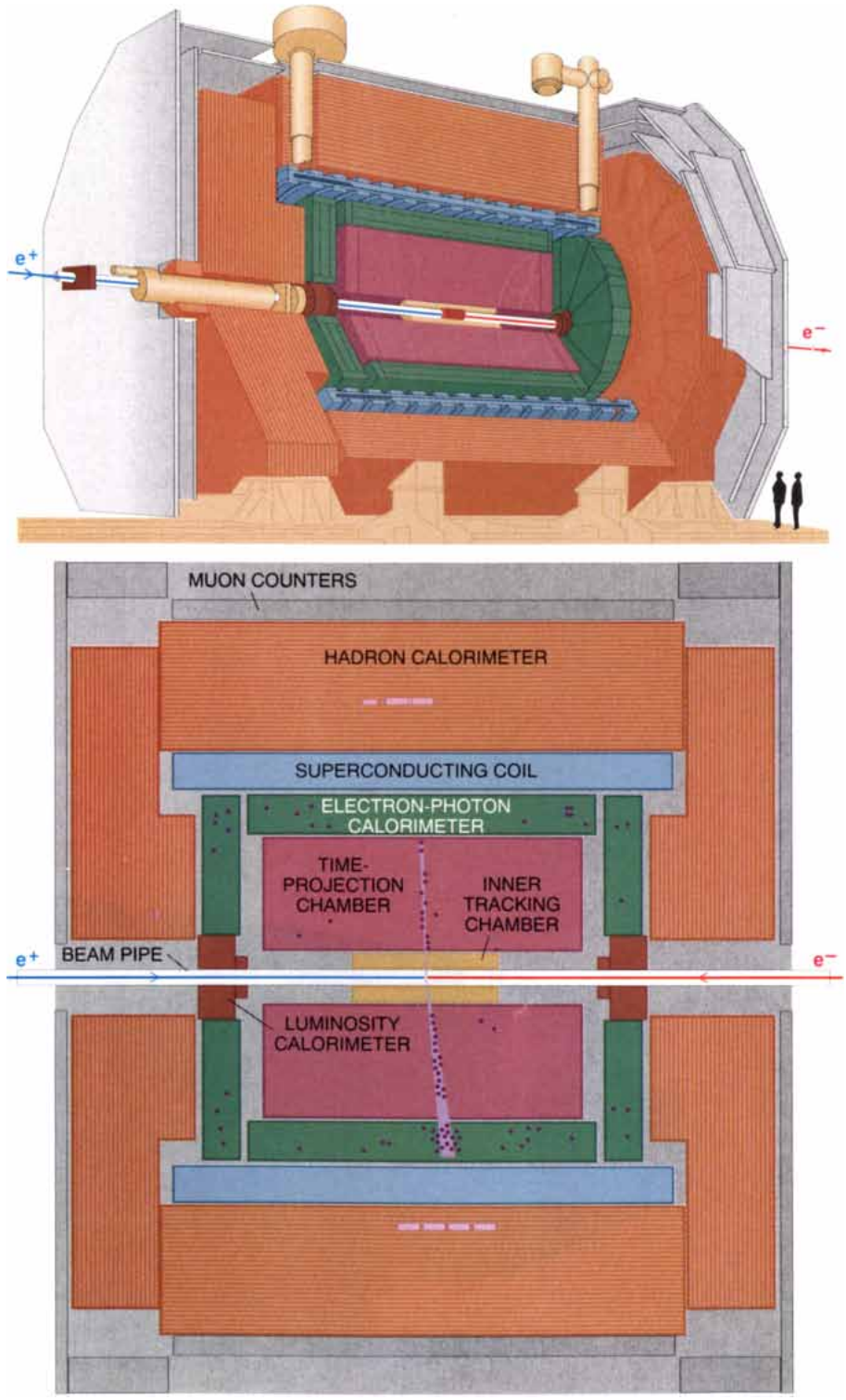
Unfortunately, neutrinos are hard to detect because they do not engage in electromagnetic or strong interactions. They touch matter only through forces that are called "weak," with good reason: most neutrinos pass through the earth without interacting. In the experiments we shall describe, the existence of neutrinos is sought indirectly.

The process begins by creating Z particles. The Z can be produced by an electron-positron pair whose combined kinetic energies make up the difference between their rest masses (expressed in equivalent energy) and the rest mass of the Z. Because these leptons have tiny rest masses, the beams in which they travel must each be raised to the very high energy of 45.5 billion electron volts (eV), about half the Z mass.

Now if the Z were perfectly stable, the beam energy would have to equal this value precisely to conserve energy and momentum. But such perfect stability is impossible, for if the Z can be created from particles, then it must also be free to decay back into them. In fact, the Z has many "channels" in which to decay. Each decay channel shortens the life of the Z.

Near the beginning of this article, we mentioned that the Z's short life made its mass indeterminate and that the extent of the indeterminacy could be used to number the families of matter. Let us explain why this must be so. One form of the Heisenberg uncertainty principle stipulates that the shorter the duration of a state is, the more uncertain its energy must be. Because the Z is short-lived, its energy—or equivalently, its mass—will have a degree of uncertainty. What this means is the following: the mass of any individual Z can be measured quite precisely, but different Zs will have slightly different masses. If the measured masses of many Zs are plotted, the resulting graph has a characteristic bell-like shape. The width of this shape is proportional to the speed at which the Z decays.

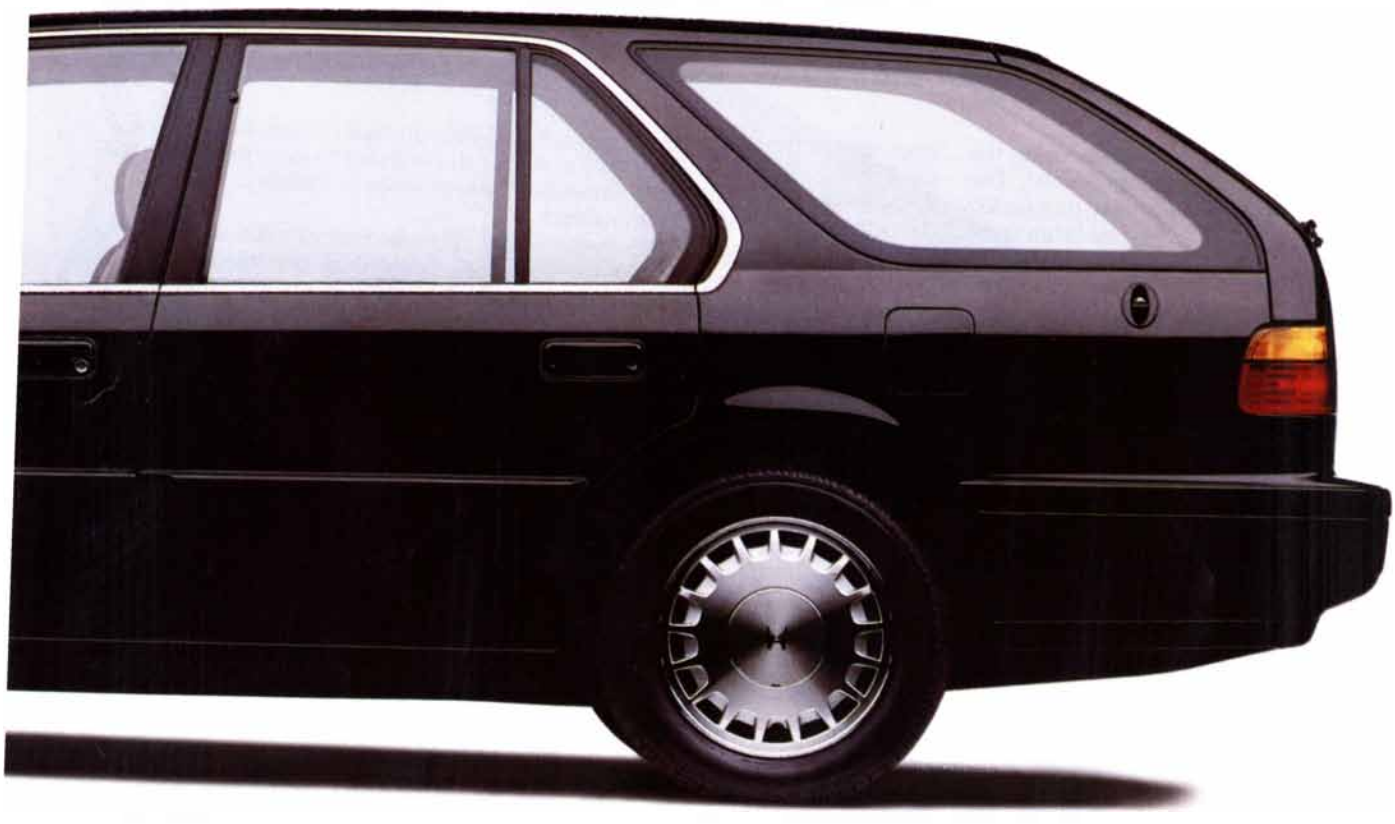
The shape is measured by varying



DETECTORS OF ALEPH are arranged in onionlike layers that feed data into computers, which can reconstruct decay events on a screen (*bottom*). Charged particles appear as tracks. The energy of both charged and neutral particles is gauged by calorimeters and graphically displayed. Aleph weighs about 4,000 tons (*top*).

We took a good idea

and built on it.



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The result is quite astonishing. This car not only holds you, your passengers and your cargo. It also holds the road.

Drive the Accord Wagon, and you'll discover the cargo area isn't all that's bigger. Beneath the low, sleek hood you'll find a 140 horsepower, 2.2 liter, 16-valve fuel-injected engine.

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The interior is built for comfort. A power moonroof gives the cabin an open, airy feeling. And there's ample head and legroom for your family. No matter how extended.

All creature comforts are thoughtfully placed within your line of sight. And your reach. Power windows, door locks and mirrors. A High-Power AM/FM stereo cassette. Air conditioning. Cruise control. And an adjustable steering column. They're all here.

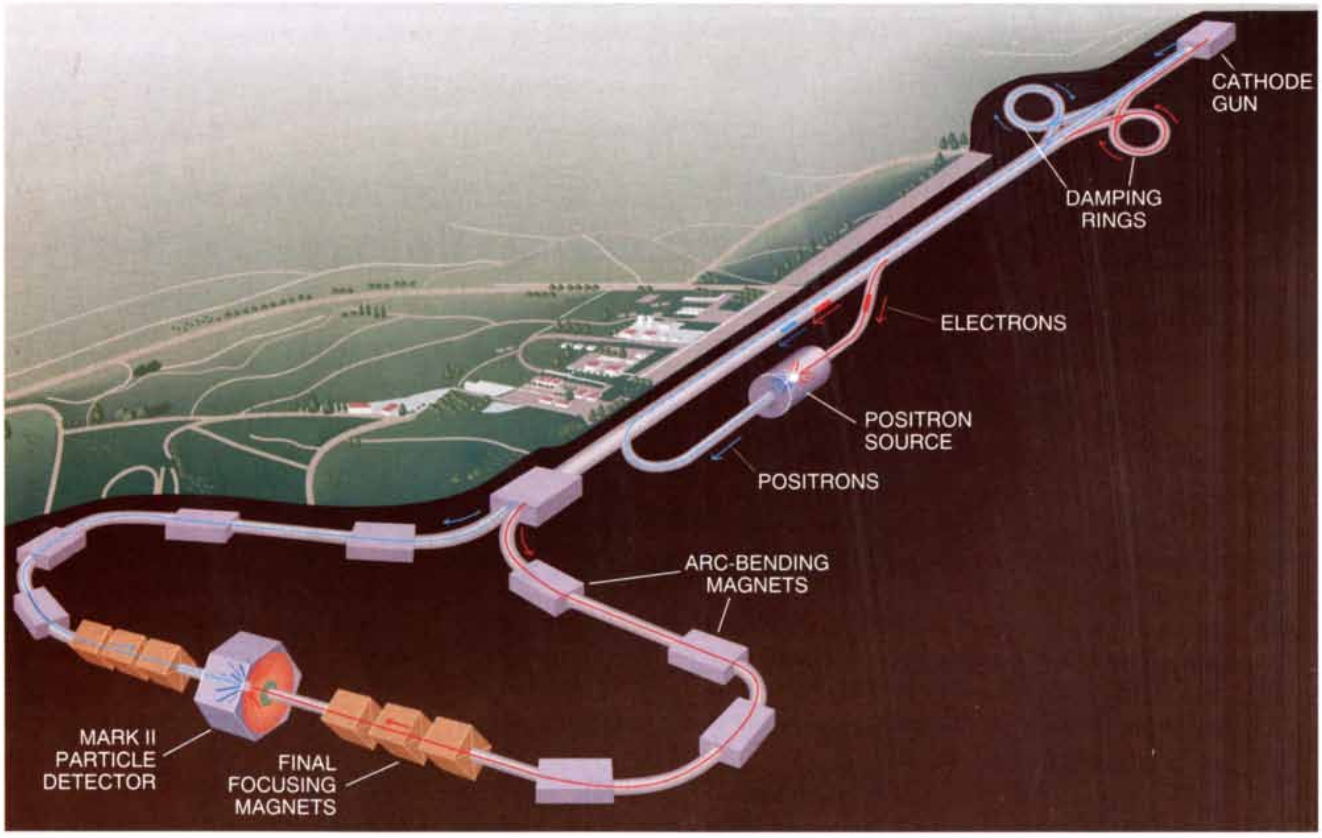
In the rear cargo area, you'll find three storage compartments. A cargo cover and cargo net. An extra wide tailgate opening. Like the interior itself, we could go on and on.

All in all, you couldn't ask for much more from a wagon. But more is what you'll get. A Supplemental Restraint System (SRS) driver's side airbag is standard equipment. As well as a remote entry system to make getting into the car easier.

The Accord Wagon. Just one more big idea. From Honda.

HONDA

The Accord Wagon



STANFORD LINEAR COLLIDER speeds positrons and electrons along a three-kilometer straightaway. The injector (*top right*) shoots electrons (*red*) into a damping ring, which condenses them for later focusing. One bunch then enters the straightaway behind a bunch of positrons (*blue*). The two bunches accelerate in tandem before entering separate arcs that focus and direct them to collision in the Mark II detector (*bottom left*). Meanwhile the second bunch of electrons slams into a target, producing positrons (*center*). The positrons are returned to the front, damped and stored.

the collision energy and observing the number of Z particles produced. The measurements trace a curve that peaks, or resonates, at a combined beam energy of about 91 billion eV. This point, called the peak cross section, defines the average Z mass. The width of the resonance curve defines the particle's mass uncertainty.

The width equals the sum of partial widths contributed by each of the Z's decay channels. The known channels are the decays to particle and antiparticle pairs of all fermions with less than one half the Z mass: the three varieties of charged leptons, the five kinds of quarks and the three varieties of neutrinos. If there are other fermions whose masses are less than half the Z mass, the Z will decay to these as well, and these channels will also contribute to the Z width, making it larger.

The present experiments show that such decays to new, charged particles do not occur, so we can be sure that the particles do not exist or that their masses are larger than half the Z mass. If, however, higher-mass families do exist, then—as we argued before—their neutrinos would still be expected to have masses much smaller than half the Z mass. Therefore, the Z would also decay to these channels, and although the neutrinos would not be seen directly in these experiments, these neutrino species would contribute to the Z width and so be observable. This is the principle enabling the experiments reported here to number the families of matter.

The electroweak theory predicts the contributions of the known channels to an accuracy of about 1 percent, as follows: for the combined quark channels, 1.74 billion eV; for each charged lepton channel, 83.5 million eV; and for each neutrino channel, 166 million eV.

As the number of assumed neutrinos (and hence families) increases, the predicted Z width also increases. The predicted peak cross section, on the other hand, declines by the square of the width [*see illustration on page 75*]. One can consequently deduce the number of families either from the measured width or from the peak cross section. The latter is statistically the more powerful measurement. The establishment of the number of families by direct experimental measurement had to await the production of large numbers of Zs by the well-understood process of electron-positron annihilation.

Researchers at CERN attacked the problem by developing the Large Electron-Positron (LEP) Collider, a traditional storage-ring design built on an unprecedented scale [see "The LEP Collider," by Stephen Myers and Emilio Picasso; SCIENTIFIC AMERICAN, July 1990]. The ring, which measures 27 kilometers in circumference, is buried between 50 and 150 meters under the plain that stretches from Geneva to the French part of the Jura Mountains [*see illustration on page 72*]. Resonance cavities accelerate the two beams with radio-frequency power. The beams move in opposite directions through a roughly circular tube. Electromagnets bend the beams around every curve and direct them to collisions in four areas, each of which is provided with a large detector.

The ring design has the advantage of storing the particles indefinitely, so that they can continue to circulate and collide. It has the disadvantage of draining the beams of energy in the form of synchroton radiation, an emission

made by any charged particle that is diverted by a magnetic field. Such losses, which at these energies appear as X rays, increase as the fourth power of the beam's energy and are inversely proportional to the ring's radius. Designers can therefore increase the power of their beams by either pouring in more energy or building larger rings, or both. If optimal use is made of resources, the cost of such storage rings scales as the square of beam energy. The LEP is thought to approach the practical economic limit for accelerators of this kind.

At Stanford, the problem of making electrons and positrons collide at high energy was attacked in a novel way in the Stanford Linear Collider (SLC). The electrons and positrons are accelerated in a three-kilometer-long linear accelerator, which had been built for other purposes. They are sent into arcs a kilometer long, brought into collision and then dumped [*see illustration on opposite page*]. The electrons and positrons each lose about 2 percent of their energy because of synchrotron radiation in the arcs, but this loss is tolerable because the particles are not recirculated. A single detector is placed at the point of collision [see "The Stanford Linear Accelerator," by John R. Rees; SCIENTIFIC AMERICAN, October 1989].

The LEP is an efficient device: when the electron and positron beams recirculate, about 45,000 collisions per second occur. The SLC beams collide, at the most, only 120 times per second. Thus, the SLC must increase its efficiency. This task can be accomplished by reducing the beam's cross section to an extremely small area. The smaller the cross section of the area becomes, the more likely it is that an electron will collide head-on with a positron. The SLC has produced beam diameters of four-millionths of a meter, about one fifth the thickness of a human hair.

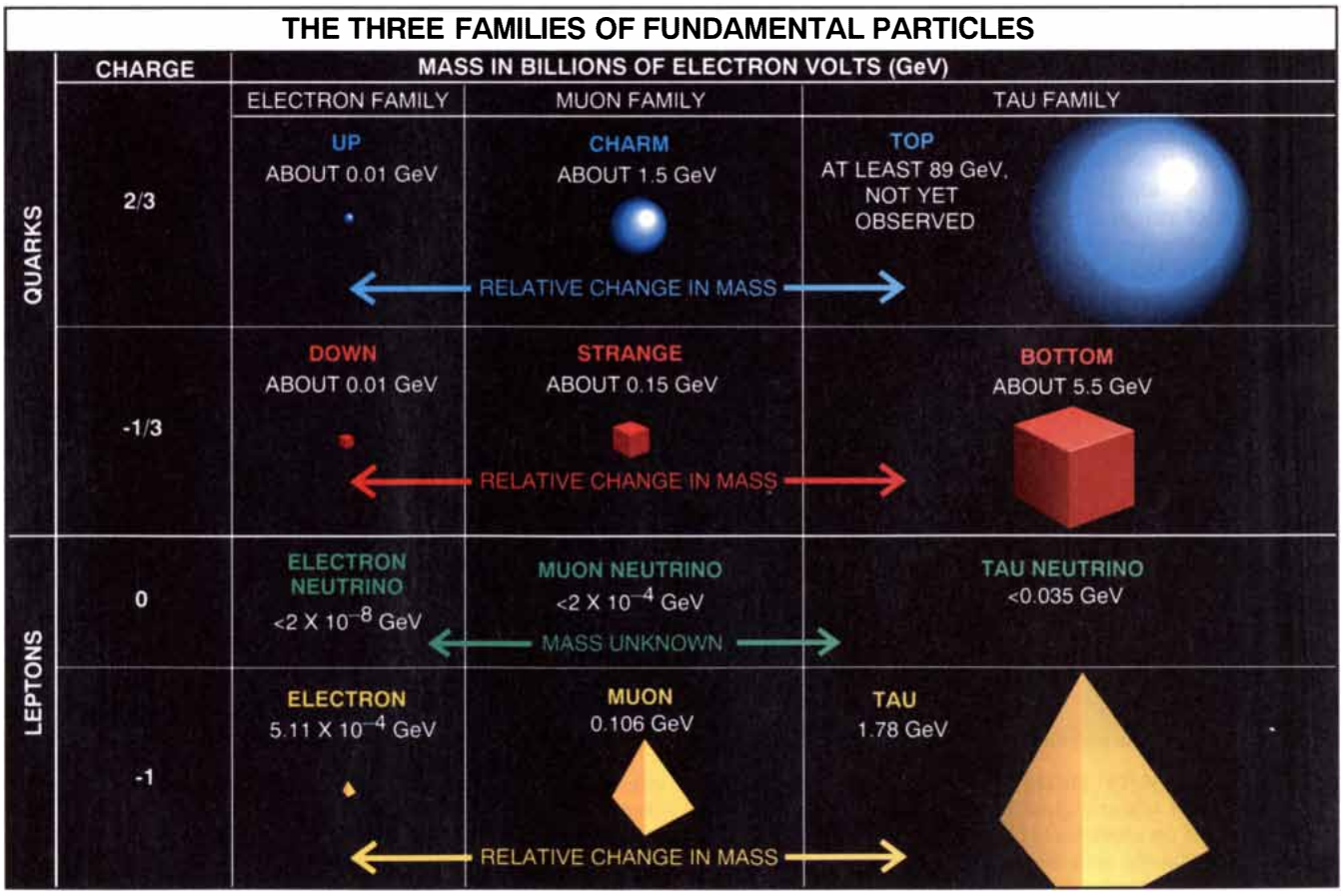
One of the main justifications for building the SLC was that it would serve as a prototype for this new kind of collider. Indeed, the SLC has shown that useful numbers of collisions are obtainable in linear colliders, and it has thus encouraged developmental research in this direction, both at SLAC and at CERN. The present Z production rates at the SLC are, however, still more than 100 times smaller than those at the LEP.

Large teams of physicists analyze the collision products in big detectors. The SLC's detector is called Mark II, and the LEP's four detectors are called Aleph, Opal, Delphi and L3 [*see illustration on page 28*]. The SLAC team numbers about 150 physicists; each of the CERN teams numbers about 400 people, drawn from research institutes and universities of two dozen countries.

The function of a detector is to measure the energies and directions of as many as possible of the particles constituting a collision event and to identify their nature, particularly that of the charged leptons. Detectors are made in onionlike layers, with tracking devices on the inside and calorimeters on the outside. Tracking devices measure the angles and momenta of charged particles. The trajectories are located by means of the ionization trails the collision products leave behind in a suitable gas. Other media, such as semiconductor detectors and light-emitting plastic fibers, are also used.

The tracking devices are generally placed in strong magnetic fields that bend the particles' trajectories inversely with respect to their momenta. Measurement of the curves yields the momenta, which in turn provide close estimates of the energy. (At the energies encountered in these experiments, the energy and the momentum of a particle differ very little.)

Calorimeters measure the energies of both neutral and charged particles by dissipating these energies in successive secondary interactions in some dense medium. This energy is then sampled in a suitable way and localized as precisely as the granularity of the calorimeter allows. Calorimeters perform their function in a number of ways. The



most common method uses sandwiches of thin sheets of dense matter, such as lead, uranium or iron, which are separated by layers of track-sensitive material.

Particles leave their mark in such materials by knocking electrons from their atoms. Argon, either in liquid form or as a gas combined with organic gases, is the usual medium. Plastic scintillators work differently: when a reaction particle traverses them, it produces a flash of light whose intensity is then measured. The calorimeter usually has two layers, an inner one optimized for the measurement of electrons and photons and an outer one optimized for hadrons.

To gather all the reaction products, the ideal detector would cover the entire solid angle surrounding the interaction point. Such detectors were pioneered in the 1970s at SLAC. In the LEP's Aleph detector the tracking of the products from the annihilation of a positron and an electron proceeds in steps.

A silicon-strip device adjoining the reaction site fixes the forward end point of each trajectory to within ten-millionths of a meter (about half the breadth of a human hair). Eight layers of detection wires then track the trajectory through an inner chamber 60 centimeters in diameter. Finally, a so-called time-projection chamber, 3.6 meters in diameter, uses a strong electric field to collect electrons knocked from gas molecules by the traversing particles. The field causes the electrons to drift to the cylindrical chambers' two ends, where they are amplified and detected on 50,000 small pads. Each electron's point of origin is inferred from the place it occupies on the pads and the time it takes to get there.

The next step outward brings the reaction products to the electron-photon calorimeter. The products traverse the superconducting coil, which creates a 15,000-gauss magnetic field at the axis of the device, and then enter the hadron calorimeter. This device, a series of iron plates separated by gas counters, also returns the magnetic flux, just as an iron core does in a conventional electromagnet. Aleph weighs 4,000 tons and cost about $60 million to build. Half a million channels of information must be read for each event, and the computer support necessary for the acquisition and later evaluation of the data is considerable [*see illustration on page 72A*].

The data gathered in the first few months of operation of the two colliders have provided the best support yet adduced for the predictions of the electroweak theory. More important, they have delineated the curve describing the *Z* width with great precision.

The overwhelming majority of observed electron-positron annihilations give rise to four sets of products: 88 percent produce a quark and an antiquark; the remaining 12 percent are divided equally among the production of a tau lepton and antitau lepton, muon and antimuon, and electron and positron. (The last case simply reverses the initial annihilation.)

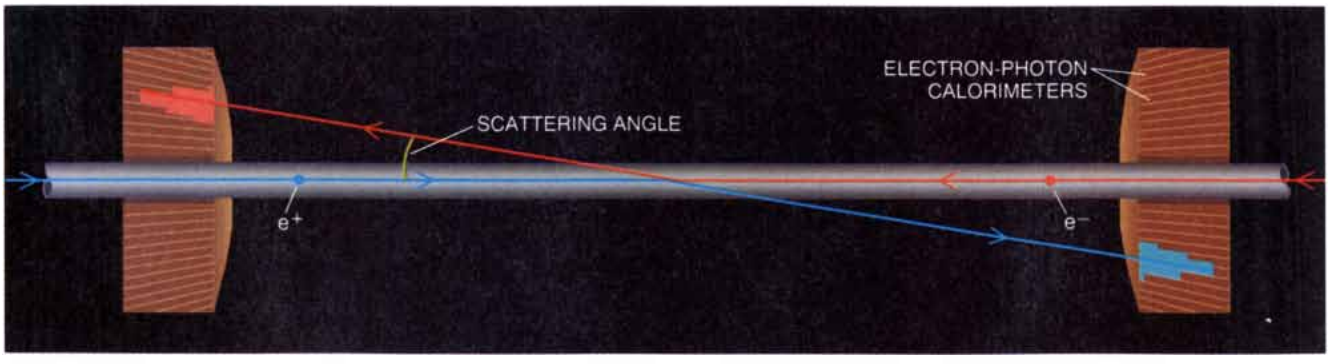
In the decays into electrons and muons, two tracks are seen back to back, with momenta (and energies) corresponding to half of the combined beam energy. The two products are easily distinguished by their distinct behavior in the calorimeters. The decays to tau leptons are more complex because they subsist for a mere instant—during which they travel about a millimeter—before decaying into tertiary particles that alone can be observed. A tau lepton leaves either closely packed tracks or just one track; in both cases, the signature is mirrored by that of another tau lepton moving in the opposite direction (thus conserving momentum).

The quarks that account for most reactions cannot be seen in their free, or "naked," state, because at birth they undergo a process called hadronization. Each quark "clothes" itself in a jet of hadrons, numbering 15 on average, two thirds of which are charged. This, the most complex of the four main decay events, usually manifests itself as back-to-back jets, each containing many tracks [*see bottom left of illustration on page 71*]. The results described here are based on the analysis of about 80,000 *Z* decays into quarks—the combined result of the four LEP teams and the one SLAC team.

The *Z* production curve is determined in an energy scan. Production probability is measured at a number of energies: at the peak energy, as well as above and below it. A precise knowledge of the beam energy is of great importance here. It was obtained at the two colliders very differently, in both cases with a good deal of ingenuity and with a precision of three parts in 10,000.

As was pointed out earlier, the total width of the *Z* resonance can be determined from either the height at the peak energy or the width of the resonance curve. The height has the smaller statistical error but requires knowledge not only of the rate at which events occur but also of the rate at which particles from the two beams cross. The latter rate is called the luminosity of the collider.

In the simple case of two perfectly aligned beams of identical shape and size, the luminosity equals the product of the number of electrons and the number of positrons in each crossing bunch, multiplied by the number of bunches crossing each second, divid-



ALEPH'S LUMINOSITY DETECTOR registers a small-angle scattering event when a positron (e^+) enters from the left and glances off an electron (e^-) entering from the right. The particles then hurtle into fine-grained calorimeters that fix their angles and measure their energies. The rate of these events measures the LEP's collision frequency, or luminosity. One must know the luminosity to determine how changes in beam energy affect the probability of producing *Z* bosons. This probability function, in turn, predicts the number of neutrino varieties, hence the number of families of matter.

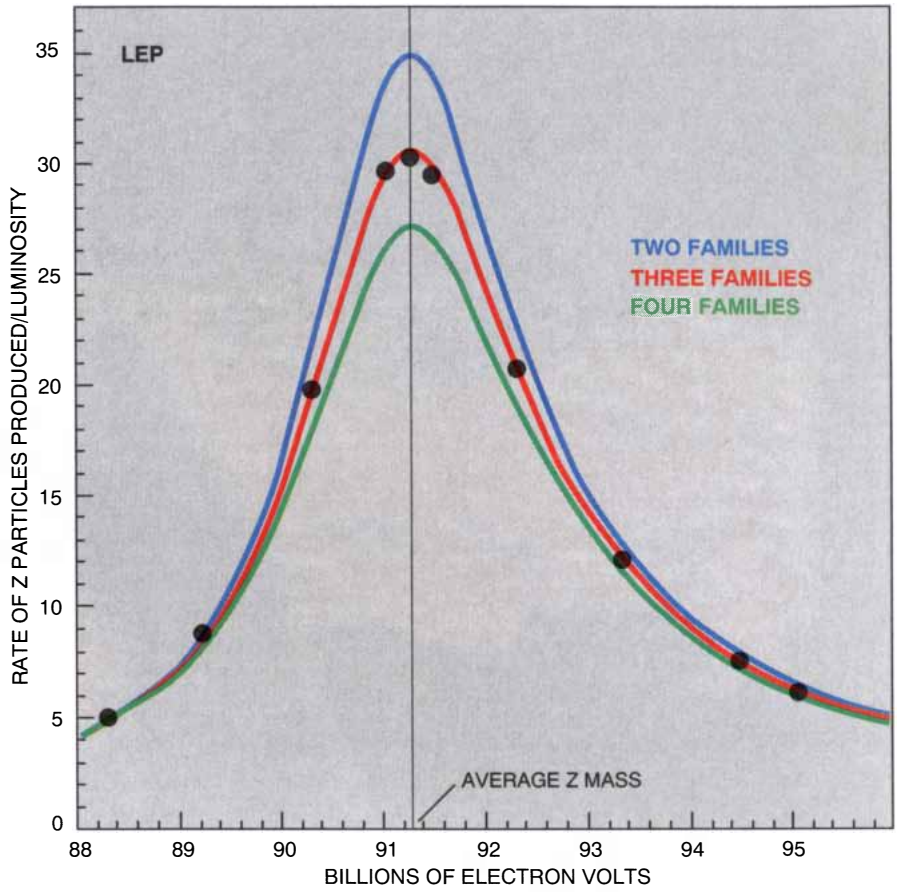
ed by the cross-sectional area of the beams. In practice, luminosity is determined only by observing the rate of the one process that is known with precision: the scattering of electrons and positrons that glance off one another at very small angles without combining or otherwise changing state. To record such so-called elastic collisions, two special detectors are placed in small angular regions just off the axis of the beam pipe. One of the detectors is in front of the collision area; the other is behind it. In the case of Aleph, these detectors are electron-photon calorimeters of high granularity [*see illustration on opposite page*].

The elastically scattered electrons and positrons are identified by the characteristic pattern in which they deposit energy in the detectors and by the way they strike the two detectors back to back, producing a perfectly aligned path. The essence here is to understand precisely the way in which particles are registered, especially in those parts of the detectors that correspond to exceedingly small scattering angles. This is important because the detection rate is extremely sensitive to changes in the angle.

When the resulting data are fitted to the theoretical resonance shape, three parameters are considered: the height at the peak, the total width and the *Z* mass. The data, in fact, agree well with the shape of the theoretically expected distribution. The next step, then, is to determine the number of neutrino families from two independent parameters—the width and the peak height.

The combined results of the five teams produced an average estimate of 3.09 neutrino varieties, with an experimental uncertainty of 0.09. This number closely approaches an integer, as it should, and matches the number of neutrino varieties that are already known. A fourth neutrino could exist without contradicting these findings only if its mass exceeded 40 billion eV—a most unlikely possibility, given the immeasurably small masses of the three known neutrinos.

The *Z* result fits the cosmological evidence gathered by those who study matter on galactic and supergalactic scales. Astronomers have measured the ratio of hydrogen to helium and other light elements in the universe. Cosmologists and astrophysicists have tried to infer the processes by which these relative abundances came about [see "Particle Accelerators Test Cosmological Theory," by David N. Schramm and Gary Steigman; SCIENTIFIC AMERICAN, June 1988].



RESONANCE CURVES predicted for the *Z* particle vary according to the number of families of matter. Thousands of *Z* decays into quarks, observed at CERN, appear as points. The measurements agree with the expectation for three families of matter.

Shortly after the big bang, the cataclysmic explosion that created the universe and began its expansion, matter was so hot that a neutron was as likely to decay into a proton-electron pair as the latter was to combine to form a neutron. Consequently, as many neutrons as protons existed. But as the universe expanded and cooled, the slightly heavier neutrons changed into protons more readily than protons changed into neutrons. The neutron-proton ratio therefore fell steadily.

When the expansion brought the temperature of the universe below one billion kelvins, protons and neutrons were for the first time able to fuse, thereby forming some of the lighter elements, mainly helium. The resulting abundances depend critically on the ratio of neutrons to protons at the time light elements were forming. This ratio, in turn, depends on the rate at which the universe expanded and cooled. At this stage, each light neutrino family—that is, any whose constituents have a mass smaller than about a million eV—contributes appreciably to the energy density and cooling rate. The measured abundances of light elements are consistent with cosmological models that assume the existence of three light neutrino families but tend to disfavor those that assume four or more.

Many questions remain unanswered. Why are there just three families of particles? What law determines the masses of their members, decreeing that they shall span 10 powers of 10? These problems lie at the center of particle physics today. They have been brought one step closer to solution by the numbering of the families of matter.

FURTHER READING

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Joseph Jachna, *Door County*

"Vision is the art
of seeing things invisible."

Jonathan Swift

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The Physiology of Perception

The brain transforms sensory messages into conscious perceptions almost instantly. Chaotic, collective activity involving millions of neurons seems essential for such rapid recognition

by Walter J. Freeman

When a person glimpses the face of a famous actor, sniffs a favorite food or hears the voice of a friend, recognition is instant. Within a fraction of a second after the eyes, nose, ears, tongue or skin is stimulated, one knows the object is familiar and whether it is desirable or dangerous. How does such recognition, which psychologists call preattentive perception, happen so accurately and quickly, even when the stimuli are complex and the context in which they arise varies?

Much is known about the way the cerebral cortex, the outer rind of the brain, initially analyzes sensory messages. Yet investigations are only now beginning to suggest how the brain moves beyond the mere extraction of features—how it combines sensory messages with past experience and with expectation to identify both the stimulus and its particular meaning to the individual.

My own group's studies, carried out over more than 30 years at the University of California at Berkeley, suggest that perception cannot be understood solely by examining properties of individual neurons, a microscopic approach that currently dominates neuroscience research. We have found that perception depends on the simultaneous, cooperative activity of millions of neurons spread throughout expanses of the cortex. Such global activity can be identified, measured and explained only if one adopts a macroscopic view alongside the microscopic one.

There is an analogy to this approach in music. To grasp the beauty in a choral piece, it is not enough to listen to the individual singers sequentially. One must hear the performers together, as they modulate their voices and timing in response to one another.

Our studies have led us as well to the discovery in the brain of chaos—complex behavior that seems random but actually has some hidden order. The chaos is evident in the tendency of vast collections of neurons to shift abruptly and simultaneously from one complex activity pattern to another in response to the smallest of inputs.

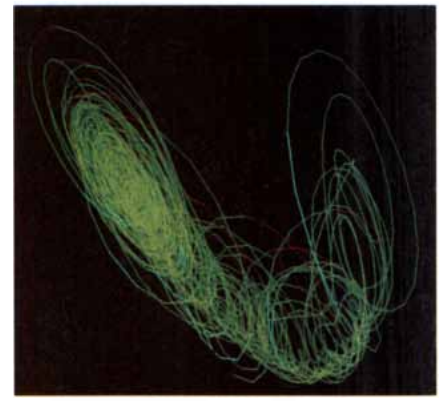
This changeability is a prime characteristic of many chaotic systems. It is not harmful in the brain. In fact, we propose it is the very property that makes perception possible. We also speculate that chaos underlies the ability of the brain to respond flexibly to the outside world and to generate novel activity patterns, including those that are experienced as fresh ideas.

An understanding of perception must be based on knowledge of the properties of the neurons that enact it. My colleagues and I have concentrated in many of our studies on neurons of the olfactory system.

For years it has been known that when an animal or a person sniffs an odorant, molecules carrying the scent are captured by a few of the immense number of receptor neurons in the nasal passages; the receptors are somewhat specialized in the kinds of odorants to which they respond. Cells that become excited fire action potentials, or pulses, which propagate through projections called axons to a part of the cortex known as the olfactory bulb. The number of activated receptors indicates the intensity of the stimulus, and their location in the nose conveys the nature of the scent. That is, each scent is expressed by a spatial pattern of receptor activity, which in turn is transmitted to the bulb.

The bulb analyzes each input pattern and then synthesizes its own message, which it transmits via axons to another part of the olfactory system, the olfactory cortex. From there, new signals are sent to many parts of the brain—not the least of which is an area called the entorhinal cortex, where the signals are combined with those from other sensory systems. The result is a meaning-laden perception, a gestalt, that is unique to each individual. For a dog, the recognition of the scent of a fox may carry the memory of food and expectation of a meal. For a rabbit, the same scent may arouse memories of chase and fear of attack.

Such knowledge has provided a valuable starting point for more detailed study of olfaction. But it leaves two important issues unresolved. The first is the classic problem of separating fore-



"PHASE PORTRAITS" made from electroencephalograms (EEGs) generated by a computer model of the brain reflect the overall activity of the olfactory system at rest (*above*) and during perception of a familiar scent (*right*). Resemblance of the portraits to irregularly shaped, but still structured, coils of wire reveals that brain activity in both conditions is chaotic: complex but having some underlying order. The more circular shape of the right-hand image, together with its greater segregation of color, indicates that olfactory EEGs are more ordered—more nearly periodic—during perception than during rest.

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ground from background: How does the brain distinguish one scent from all others that accompany it?

Also, how does the brain achieve what is called generalization-over-equivalent receptors? Because of turbulence in nasal air flow, only a few of the many receptors that are sensitive to an odorant are excited during a sniff, and the selection varies unpredictably from one sniff to the next. How does the brain recognize that signals from different collections of receptors all refer to the same stimulus? Our investigations begin to suggest answers to both problems.

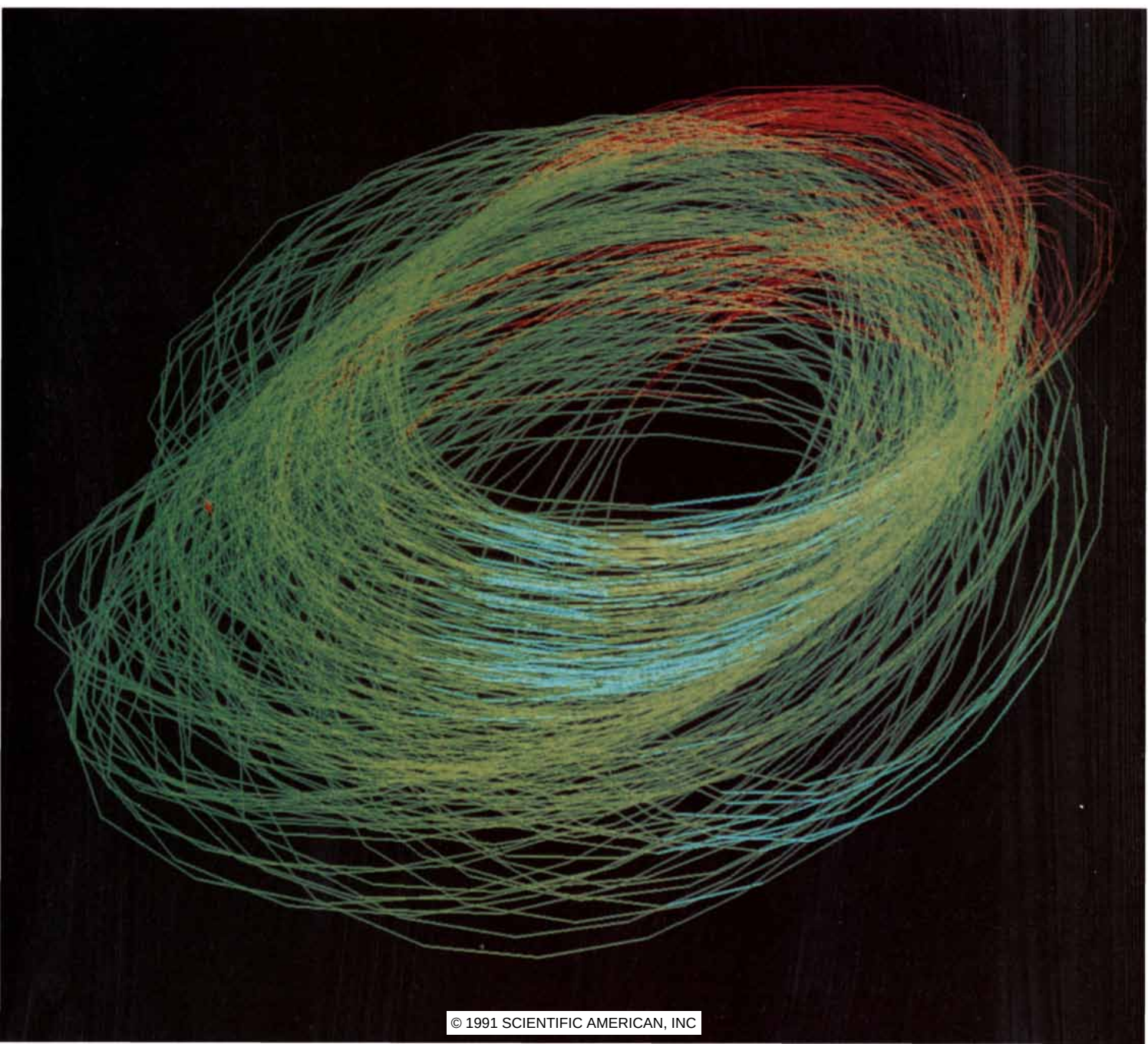
Many of our insights were derived from intensive studies of the olfactory bulb. Those experiments show clearly that every neuron in the bulb participates in generating each olfactory perception. In other words, the salient information about the stimulus is carried in some distinctive pattern of bulbwide activity, not in a small subset of feature-detecting neurons that are excited only by, say, foxlike scents.

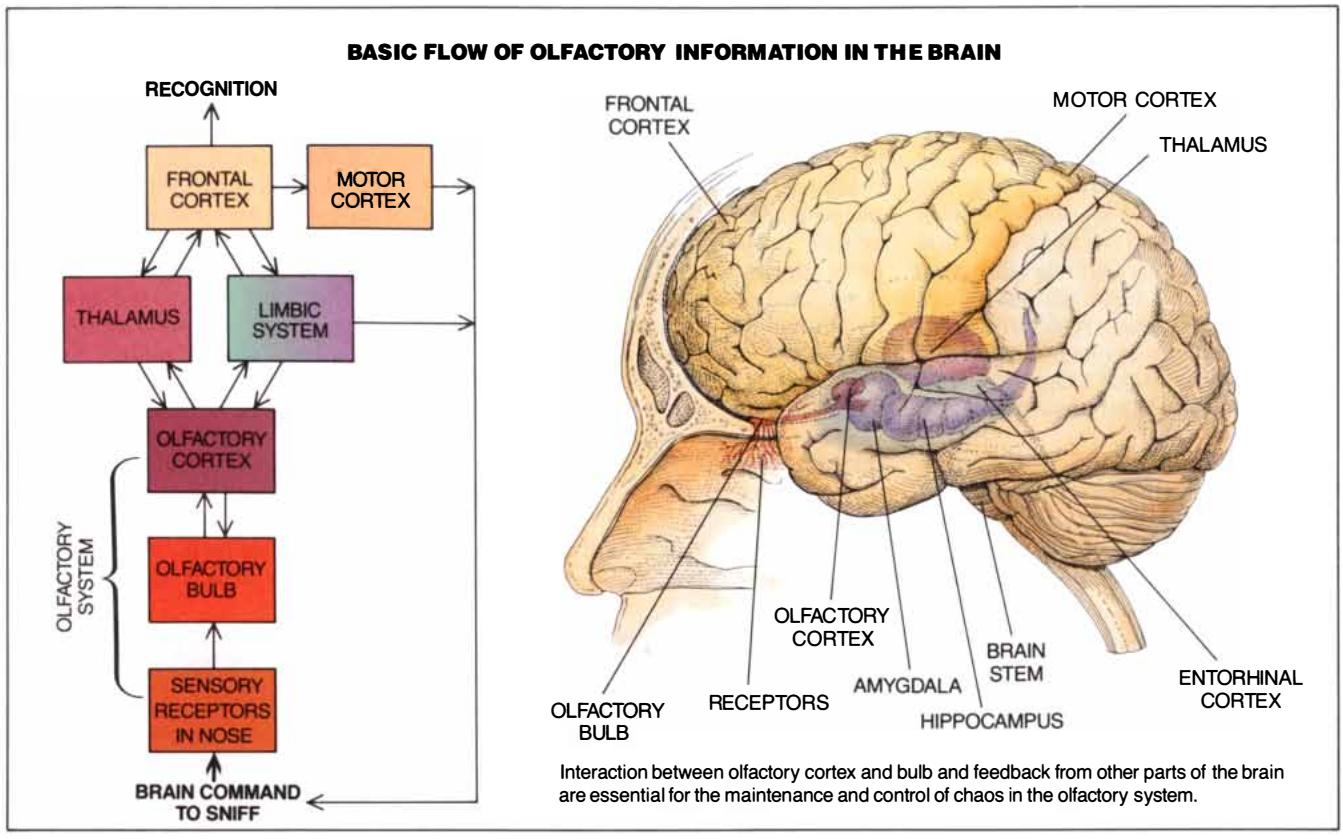
Moreover, although this collective neural activity reflects the odorant, the activity itself is not determined solely by the stimulus. Bulbar functioning is self-organized, very much controlled by internal factors, including the sensitivity of the neurons to input.

The experiments uncovering the collective activity were conceptually simple. By applying standard reinforcement techniques, we trained animals, often rabbits, to recognize several different odorants and to behave in particular ways when they did—for instance, to lick or chew in expectation of food or water. Before training was started, we attached 60 to 64 electrodes 0.5 millimeter apart in a gridlike array to a large part of the bulbar surface.

During training and thereafter, the array enabled us to collect sets of 60 to 64 simultaneously recorded electroencephalogram (EEG) tracings as the animals breathed in and out, sometimes sniffing familiar scents and sometimes not. Each tracing reflects the mean excitatory state of local pools of neurons lying in a well-defined layer immediately beneath the electrodes. Rises in the wavelike tracings indicate increasing excitement; dips represent diminished excitement caused by inhibition.

The EEGs should not be confused with recordings of impulses fired by individual axons or by pools of neurons, although each EEG is related to the





Interaction between olfactory cortex and bulb and feedback from other parts of the brain are essential for the maintenance and control of chaos in the olfactory system.

firing pattern of neurons in a neighborhood of the cerebral cortex. The tracings detect essentially the same information that neurons assess when they "decide" whether or not to fire impulses, but an EEG records that information for thousands of cells at once.

To better understand exactly what the EEG shows, it helps to know some of the details of how cortical neurons operate. Such cells continuously receive pulses—usually at projections known as dendrites—from thousands of other neurons. The pulses are conveyed at specialized junctions called synapses. Certain incoming pulses generate excitatory waves of electric current in the recipients; others generate inhibitory waves [*see top illustration on page 82*]. These currents—"dendritic currents"—are fed through the cell body (which contains the nucleus) to a region called the trigger zone, at the start of the axon.

There the currents cross the cell membrane into the extracellular space. As they do, the cell calculates the overall strength of the currents (reflected in changes in voltage across the membrane), essentially by adding excitatory currents and subtracting inhibitory ones. If the sum is above a threshold level of excitation, the neuron fires.

The mechanism producing each EEG tracing similarly sums the currents initiated at the dendrites, but it taps the currents after they leave the cell. The tracings reflect the excitatory state of groups of neurons rather than of individual ones, because the extracellular space is traversed by currents from thousands of cells.

In our experiments the EEG tracings from the electrodes in an array are as unpredictable and irregular as freehand scrawls. Yet they manifest perceptual information.

In living individuals, EEGs always oscillate, or rise and fall, to some extent, but the oscillations are usually quite irregular. When an animal inhales a familiar scent, what we call a burst can be seen in each EEG tracing. All the waves from the array of electrodes suddenly become more regular, or ordered, for a few cycles—until the animal exhales. The waves often have a higher amplitude (height) and frequency than they do at other times.

The burst waves are often called 40-hertz waves, meaning that they oscillate at about 40 cycles per second. Because the frequency can actually range from 20 to 90 hertz, I prefer to call them gamma waves, in analogy with a range of high-frequency X rays.

The fact that the bursts represent cooperative, interactive activity is not immediately clear in the EEG plots, because the burst segments differ in shape from tracing to tracing in a simultaneously recorded set. Nevertheless, by taxing our computers, we find we are able to tease out evidence of collective behavior from the complex background.

In each set of burst recordings, we can identify a common waveform, or carrier wave: a shared pattern of rises and falls that is embedded in each tracing. The average amplitude is not identical across the set—some versions of the carrier wave are shallow, and others are deep. But all of them curve up and down nearly in synchrony. The common behavior makes up between one quarter and three quarters of the total activity of the neurons giving rise to each trace.

Curiously, it is not the shape of the carrier wave that reveals the identity of an odor. Indeed, the wave changes every time an animal inhales, even when the same odorant is repeatedly sniffed. The identity of an odorant is reliably discernible only in the bulbwide spatial pattern of the carrier-wave amplitude [*see top illustration on page 84*].

Amplitude patterns become especially clear when we plot the average amplitude of the individual versions of the carrier wave on a grid representing the surface of the bulb. The resulting "maps" resemble contour diagrams that indicate the elevations of mountains and valleys. As long as we do not alter the animals' training, the same map emerges every time an animal sniffs a particular odorant, even though the carrier wave differs with each sniff.

These maps have helped demonstrate not only that perception requires global bulbwide activity but also that the bulb participates in assigning meaning to stimuli. The amplitude map representing a given odorant changes strikingly when we alter the reinforcement associated with that scent. If the bulb did not bring experience to bear on perception, the map would remain constant even after the conditioned association had been changed.

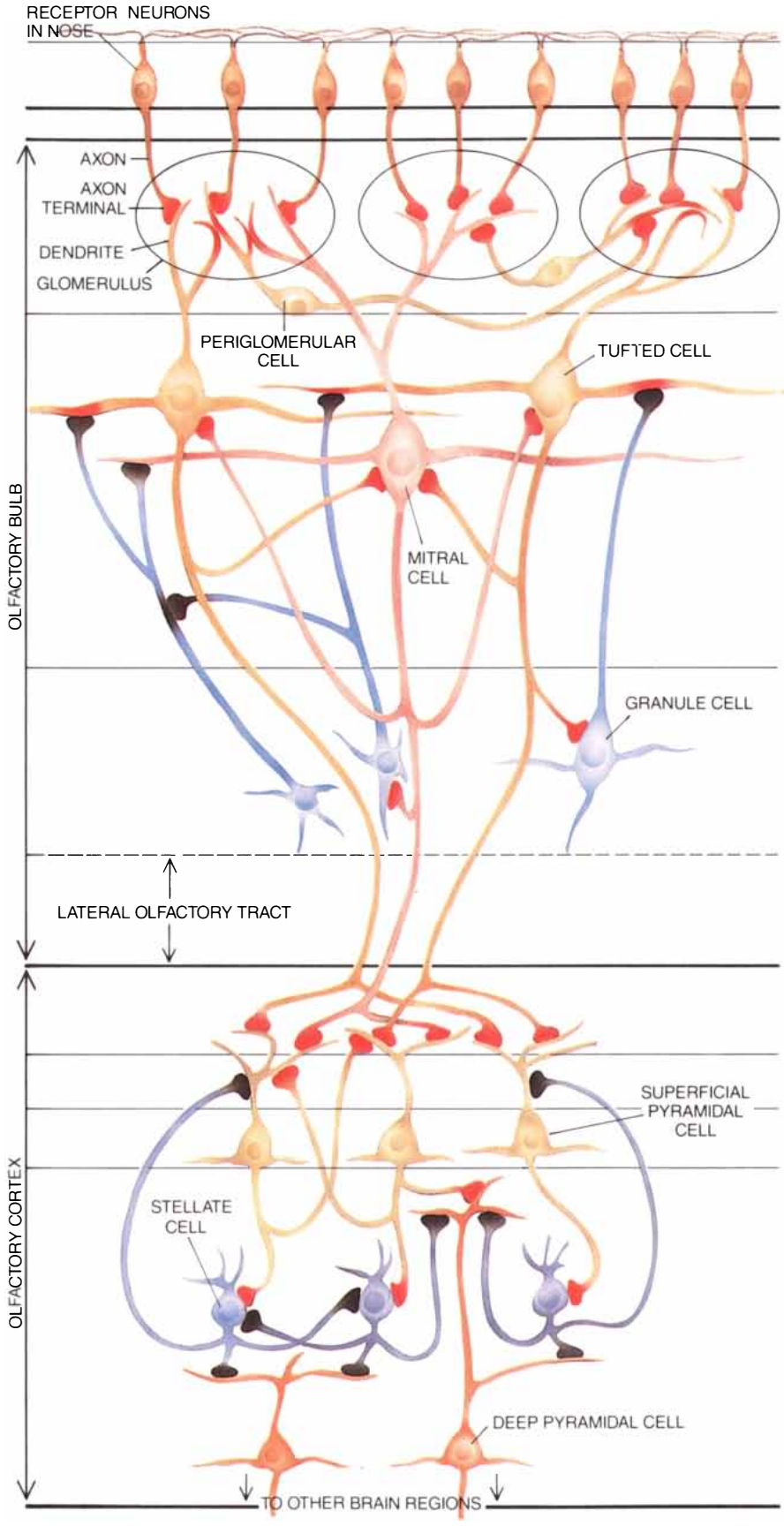
We believe that something we call the nerve cell assembly is both a crucial repository of past associations and an essential participant in the formation of the collective bulbar burst. The hypothetical assembly consists of neurons that have simultaneously been excited by other neurons during learning.

More than 20 years ago my colleagues and I discovered that when animals are trained by reinforcement techniques to discriminate olfactory stimuli, certain synapses that connect neurons within the bulb and within the olfactory cortex become selectively strengthened during the training. That is, the sensitivity of the postsynaptic cells to excitatory input—a property known as gain—is increased at the synapse, so that an input generates a greater dendritic current than it would have generated in the absence of special training. Technically, gain is the ratio of output to input—here, the net strength of the dendritic currents to the number of incoming pulses.

The strengthening occurs not in the synapse between an input axon (such as a receptor from the nose) and the neuron it excites (such as a bulbar neuron) but in the synapse between connected neurons that are simultaneously excited by input neurons during learning. Neurons in the bulb and in the olfactory cortex are connected to many others in those regions.

Such strengthening is predicted by the widely accepted Hebb rule, which holds that synapses between neurons that fire together become stronger, as long as the synchronous firing is accompanied by a reward. (The strengthening is now known to involve "modulator" chemicals that the brain stem releases into the bulb and cortex during reinforcement.)

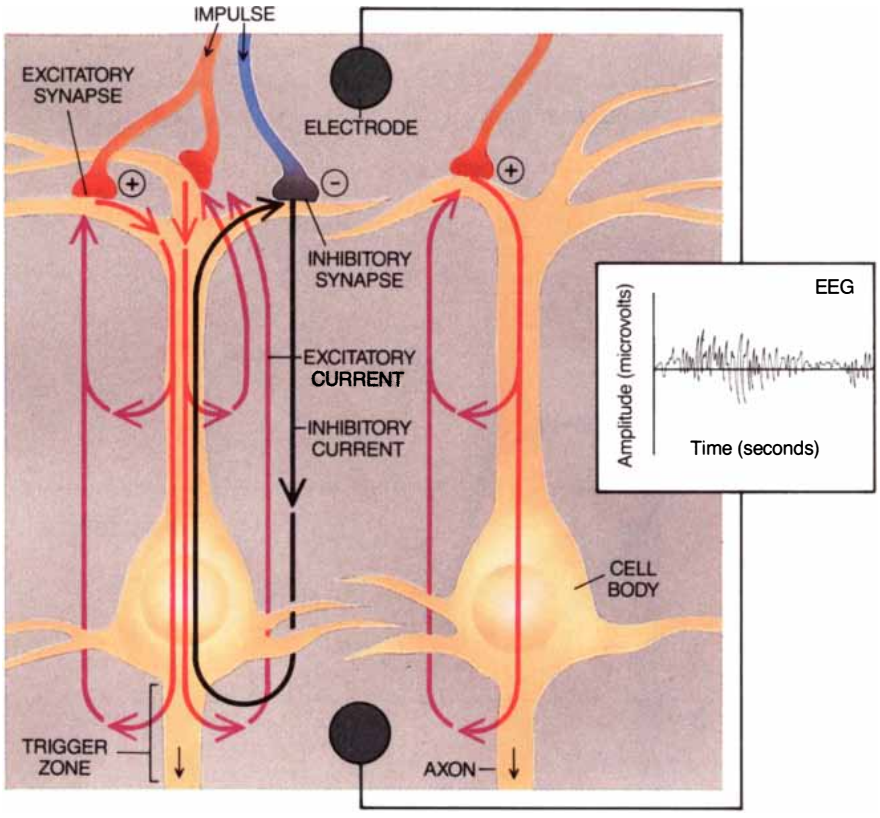
We infer from our data that a nerve cell assembly, consisting of neurons joined by Hebbian synapses, forms for a particular scent as an individual is reinforced for learning to identify that odorant. Thereafter, when any subset of neurons in the assembly receives the familiar input, the entire assembly can



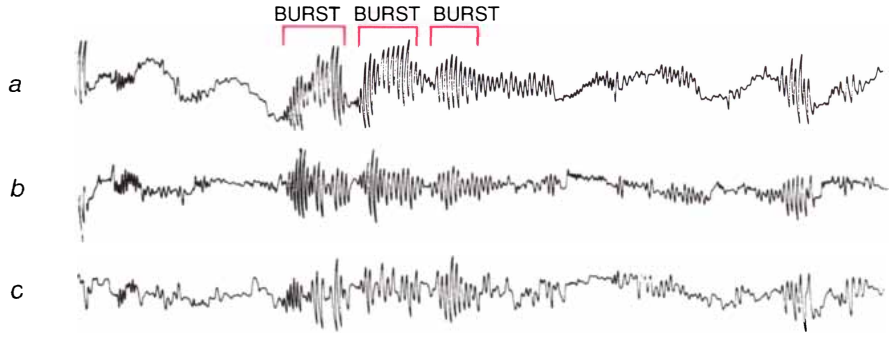
NEURONS OF THE OLFACTORY SYSTEM share information through a rich web of synapses, junctions where signals flow from neuron to neuron. Usually signals pass from projections called axons to projections called dendrites, but sometimes they pass from dendrite to dendrite or axon to axon. The widespread sharing leads to collective activity. In this highly schematic diagram, red shading signifies that a neuron is exciting another cell, black shading that a neuron is inhibiting another.

rapidly become stimulated, as excitatory signals speed across the favored Hebbian synapses. The assembly, in turn, directs the rest of the bulb into a distinct pattern of activity.

If we are correct, the existence of a nerve cell assembly would help explain both the foreground-background problem and generalization-over-equivalent receptors. In the first instance, the assembly would confer "front-runner" status on stimuli that experience, stored in the Hebbian synapses, has made important to the individual. In the second instance, the assembly would ensure that information from any subset of receptors, regardless of where in the nose they were located, would spread immediately over the entire assembly and from there to the rest of the bulb.



EEG WAVES reflect the mean excitation of pools of neurons. Excitatory inputs at synapses generate electric currents that flow in closed loops within the recipient neuron toward its axon, across the cell membrane into the extracellular space and, in that space, back to the synapse (*red arrows*). Inhibitory inputs generate loops moving in the opposite direction (*black arrows*). In cells the trigger zone adds current strengths (reflected in changes in voltage across the membrane), and it fires impulses if the sum is sufficiently positive. Electrodes on the brain tap those same currents after they leave the cell. The resulting EEGs indicate the excitation of whole groups of cells, not individuals, because the extracellular avenues from which the EEGs arise carry currents contributed by thousands of cells.



SIMULTANEOUS RECORDINGS from the olfactory bulb (*a*) and front (*b*) and rear (*c*) parts of a cat's olfactory cortex show low-frequency waves interrupted by "bursts"—high-amplitude, high-frequency oscillations that are generated when odors are perceived. The average amplitude of a burst is some 100 microvolts. Each lasts a fraction of a second, for the interval between inhalation and exhalation.

As important as the nerve cell assembly is to perception, it does not by itself generate bulbwide bursts of collective activity. For a burst to occur in response to some odorant, the neurons of the assembly and the bulb as a whole must first be "primed" to respond strongly to input.

Two important processes complement the priming accomplished by the development of Hebbian synapses. Both processes affect the gain, doing so by altering the sensitivity of the trigger zones, not the synapses. Here the gain is the ratio of the number of pulses fired (output) to the net dendritic current (input). The total gain is the product of the gain at the synapses and trigger zones.

One primer is general arousal. Our experiments show that the gain in neuronal collectives increases in the bulb and olfactory cortex when an animal is hungry, thirsty, sexually aroused or threatened [*see illustration on page 85*]. Such priming seems to be accomplished by axons from elsewhere in the brain that release modulatory chemicals (other than those involved in forming Hebbian synapses).

The other primer is input itself. When cortical neurons are excited, their output increases. Each new input they receive while they are still excited raises their output markedly, indicating that their gain has been increased by the input. This increase occurs over a particular range of input. If the net input is strongly inhibitory, no pulses are fired. Above some very high level of excitatory input, neurons fire at their maximal rate and cannot do more, even if the input is increased. In the wide range between, however, pulse output increases along a sigmoid (S-shaped) curve. The steepness, or slope, of the curve reflects the gain.

The discovery of an increase in gain with excitation is particularly noteworthy because most neural network models assume neurons are at maximum gain when they are at rest. Both excitation and inhibition are generally assumed to decrease gain, so that the networks constantly maintain stability. Such assumptions are inappropriate for the brain because they do not allow networks to generate explosive changes.

Hence, it seems that information from odorants is fed by a small number of receptors to a still smaller num-

ber of cells in the bulb. If the odorant is familiar and the bulb has been primed by arousal, the information spreads like a flash fire through the nerve cell assembly. First, excitatory input to one part of the assembly during a sniff excites the other parts, via the Hebbian synapses. Then those parts reexcite the first, increasing the gain, and so forth, so that the input rapidly ignites an explosion of collective activity throughout the assembly. The activity of the assembly, in turn, spreads to the entire bulb, igniting a full-blown burst.

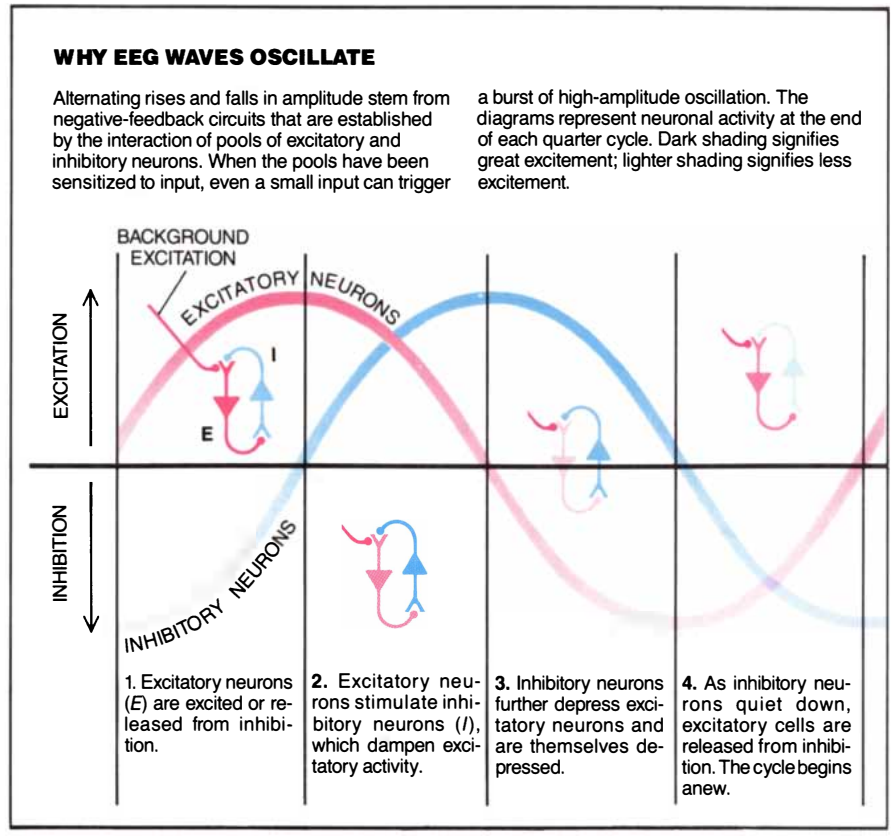
The bulb then sends a "consensus statement" simultaneously along parallel axons to the olfactory cortex. What must next be made clear is how that cortical area distinguishes the consensus statement from the background of other stimuli impinging on it from the bulb and elsewhere.

The answer undoubtedly has to do with the wiring joining the bulb to the cortex. The bulb generates trains of impulses that run simultaneously along the parallel axons leading from the bulb to the cortex. Each axon branches extensively and transmits pulses to many thousands of neurons across the olfactory cortex, and each cortical target cell receives input from thousands of bulbar cells.

The carrier activity of the incoming lines, which is synchronized by cooperation, probably stands out for the simple reason that such signals add together; nonsynchronous inputs, which are not at the carrier frequency and phase, effectively cancel one another. Thus, every recipient neuron in the olfactory cortex picks up a share of the cooperative bulbar signal and transmits the summed signals to thousands of its neighbors simultaneously.

In response, the massively connected neurons of the cortex, which have formed their own nerve cell assemblies, promptly generate their own collective burst, albeit one having a carrier wave and a spatial amplitude pattern that differ from those in the bulb. In essence, the transmission pathway for the global pattern in the bulb launders the bulbar message; it removes "noise," so that only the collective signal affects the olfactory cortex significantly. Just as a burst in the bulb guarantees the delivery of a coherent message to the cortex, so presumably does the global burst in the cortex enable outgoing messages from that region to stand above the din when they reach other regions of the brain.

There are many reasons why we believe the activity of the brain both during and between bursts is chaotic, not merely random. But before I delve into those reasons, let me clarify further what is meant by chaos.



At the risk of oversimplification, I sometimes like to suggest the difference between chaos and randomness by comparing the behavior of commuters dashing through a train station at rush hour with the behavior of a large, terrified crowd. The activity of the commuters resembles chaos in that although an observer unfamiliar with train stations might think people were running every which way without reason, order does underlie the surface complexity: everyone is hurrying to catch a specific train. The traffic flow could rapidly be changed simply by announcing a track change. In contrast, mass hysteria is random. No simple announcement would make a large mob become cooperative.

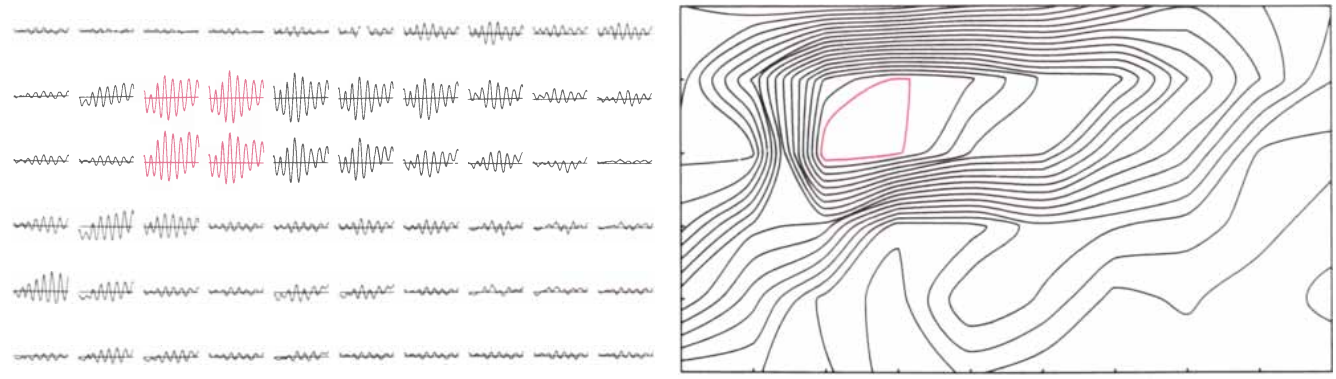
One of the most convincing early clues to the presence of chaos was an aperiodic (nonrepeating) common carrier wave everywhere in the bulb not only during bursts but also between bursts—even when there was no extrabulbar stimulus driving that collective activity. The lack of external driving meant the activity was self-generated by the bulb. Such self-organization is a characteristic of chaotic systems [see "Chaos," by James B. Crutchfield, J. Doyne Farmer, Norman H. Packard and Robert S. Shaw; SCIENTIFIC AMERICAN, December 1986].

Another clue was the apparent ability of neural collectives in the bulb and cortex to jump globally and almost instantly from a nonburst to a burst state and then back again. Rapid state changes are called phase transitions by physicists and bifurcations by mathematicians. Whatever they are called, dramatic changes in response to weak input are, it will be recalled, another feature of chaotic systems. Bifurcation is significantly harder to control in random systems.

We gained more evidence for chaos by developing computer models of the olfactory system as a whole: the bulb, the cortex, the connections between them and the input to both areas from outside the system. We simulated the activity of the system by solving sets of ordinary differential equations that describe the dynamics of local pools of neurons.

First we demonstrated that the model did in fact represent the olfactory system accurately. With no more than a single pulse (equivalent to excitation of a few receptors) to start the system, the model sustained activity that closely resembled aperiodic olfactory EEGs.

After we "trained" the model to recognize specific odorants, the bulbar segment generated bursts in response to the selected inputs, and the embedded common carrier waves yielded distinct and consistent amplitude maps. Moreover, whenever we added a new



COMMON CARRIER WAVE emerged from 60 EEGs recorded simultaneously from the olfactory cortex of a rabbit as it recognized a scent (*left*). The wave is nearly the same in each recording, except that the amplitude varies. The shape of the carrier wave does not indicate the identity of the scent. That information is contained in the spatial pattern of amplitude across the cortex, which can be displayed as a contour plot (*right*), much like the plots of elevations in topographic maps. The colored contour represents the highest amplitude; successive contours represent progressively lower amplitudes.

"odorant" to the perceptual repertoire of our hypothetical subject, an identifying global amplitude map was created. At the same time, the other maps changed—as they should, of course, in a true associative memory system. We had earlier found such changes in test animals after they were trained to recognize stimuli beyond the ones they had learned initially.

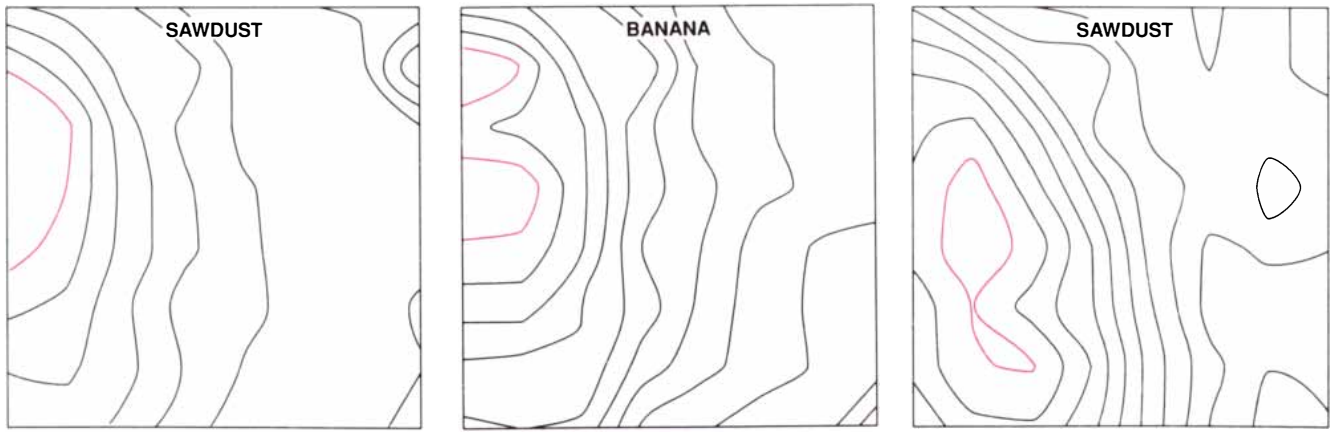
Our model yielded additional evidence for chaos when we coaxed it to produce mock EEGs of extended bursts and of "interburst" activity in the intervals between bursts. Because the artificial EEGs persisted longer than EEGs normally do, we were able to plot what are called phase portraits of the predicted behavior of the olfactory system, both during and between bursts. The portraits can show at a glance whether the dynamics may be chaotic.

The details of how such portraits are made and why they are a valid reflection of global activity in the olfactory system are too complex to discuss at length. Nevertheless, for those readers familiar with phase portraits, I should note that we plotted the portraits in a three-dimensional grid and added color to display a fourth dimension. Each axis represented EEG amplitude from some part of the olfactory system, such as the bulb or a subsection of the olfactory cortex. A range of colors from red to blue represented high to low amplitude from a fourth part of the system.

We plotted as a point one set of three amplitudes, measured at a given moment. Next we plotted another point from the set, representing a thousandth of a second later, and connected the two points with a colored line. Then we plotted a third point, and so on. We rotated the final image in space to find the most informative point of view.

The pictures supported the possibility of chaos, because the images resembled loose coils of wire having different shapes and color distributions. If the model olfactory system had behaved randomly, there would be no coherent shapes, just dots spread everywhere, like "snow" on a television set. If, on the other hand, the system was predictable in detail, the shapes would be simpler; they might resemble a spiral, a folded circle or a torus (a doughnut).

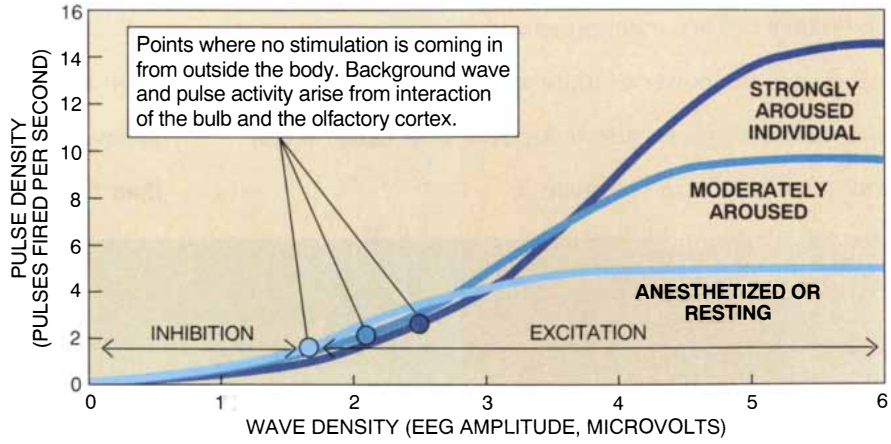
The shapes we found represent chaotic attractors. Each attractor is the behavior the system settles into when it is held under the influence of a particular input, such as a familiar odorant. The images suggest that an act of perception consists of an explosive leap of the dynamic system from the "basin" of one chaotic attractor to another; the basin of an attractor is the set of initial conditions from which the system goes into a particular behavior. The bottom



CONTOUR PLOT at the left emerged consistently from bulbar EEGs of a rabbit that had been conditioned to associate the scent of sawdust with a particular reinforcement. After the animal learned to recognize the smell of banana (*middle*), however, reexposure to sawdust led to the emergence of a new sawdust plot (*right*). The change shows that bulbar activity is dominated more by experience than by stimuli; otherwise, sawdust would always give rise to the same plot.

of a bowl would be a basin of attraction for a ball placed anywhere along the sides of the bowl. In our experiments, the basin for each attractor would be defined by the receptor neurons that were activated during training to form the nerve cell assembly.

We think the olfactory bulb and cortex maintain many chaotic attractors, one for each odorant an animal or human being can discriminate. Whenever an odorant becomes meaningful in some way, another attractor is added, and all the others undergo slight modification.



SIGMOID CURVES show the relation between input (wave density) and output (pulse density) at trigger zones in populations of neurons. (The plots are not valid for individual neurons.) The rising steepness associated with increased arousal indicates that sensitivity to input—or gain (the ratio of output to input, or the slope)—rises with arousal. In each case, gain also increases as neurons that are already excited (those at and to the right of the circles) receive more stimulation. This input-dependent increase in gain is essential to the formation of bursts.

Identification of chaos does not automatically reveal its source. We suspect chaos in the brain arises when two or more areas of the brain, such as the bulb and the olfactory cortex, meet at least two conditions: they excite one another strongly enough to prevent any single part from settling down, and, at the same time, they are unable to agree on a common frequency of oscillation. Competition between the parts would increase the sensitivity and instability of the system, contributing to chaos. Part of the evidence for the importance of interaction between the bulb and the cortex is that disconnection of the two regions makes chaos disappear; both parts become abnormally stable and quiet.

Modulatory chemicals released into the system from elsewhere in the brain also increase sensitivity to input, both by participating in the formation of the Hebbian synapses in nerve cell assemblies and by enhancing arousal. Because various factors maintain great sensitivity, a very small signal—a whiff, a whisper, a glimpse—can trigger a massive, collective state change.

Conceivably, the chaos we have observed is simply an inevitable by-product of the brain's complexity, including its myriad connections. Yet our evidence suggests that the controlled chaos of the brain is more than an accidental by-product. Indeed, it may be the chief property that makes the brain different from an artificial-intelligence machine.

One profound advantage chaos may confer on the brain is that chaotic systems continually produce novel activity patterns. We propose that such patterns are crucial to the development of nerve cell assemblies that differ from established assemblies. More generally, the ability to create activity patterns may underlie the brain's ability to generate insight and the "trials" of trial-and-error problem solving.

We have found widespread, apparently chaotic behavior in other parts of the brain. That finding does not necessarily imply that other sensory systems operate as the olfactory system does. But we think they do. Indeed, we and other investigators have documented gamma bursts across large cortical regions involved in recognizing visual images. As in the olfactory system, familiar visual stimuli are associated with specific amplitude maps of common carrier waves. I predict that when people examine drawings in which foreground and background are ambiguous, so that perception alternates between two images, the amplitude maps will be found to alternate as well.

I begin to envision the general dynamics of perception. The brain seeks information, mainly by directing an individual to look, listen and sniff. The search results from self-organizing activity in the limbic system (a part of the brain that includes the entorhinal cortex and is thought to be involved in emotion and memory), which funnels a search command to the motor systems. As the motor command is transmitted, the limbic system issues what is called a reafference message, alerting all the sensory systems to prepare to respond to new information.

And respond they do, with every neuron in a given region participating in a collective activity—a burst. Synchronous activity in each system is then transmitted back to the limbic system, where it combines with similarly generated output from other sensory systems to form a gestalt. Then, within a fraction of a second, another search for information is demanded, and the sensory systems are prepared again by reafference.

Consciousness may well be the subjective experience of this recursive process of motor command, reafference and perception. If so, it enables the brain to plan and prepare for each subsequent action on the basis of past action, sensory input and perceptual synthesis. In short, an act of perception is not the copying of an incoming stimulus. It is a step in a trajectory by which brains grow, reorganize themselves and reach into their environment to change it to their own advantage.

The poet William Blake wrote: "If the doors of perception were cleansed every thing would appear to man as it is, infinite." Such cleansing would not be desirable. Without the protection of the doors of perception—that is, without the self-controlled chaotic activity of the cortex, from which perceptions spring—people and animals would be overwhelmed by infinity.

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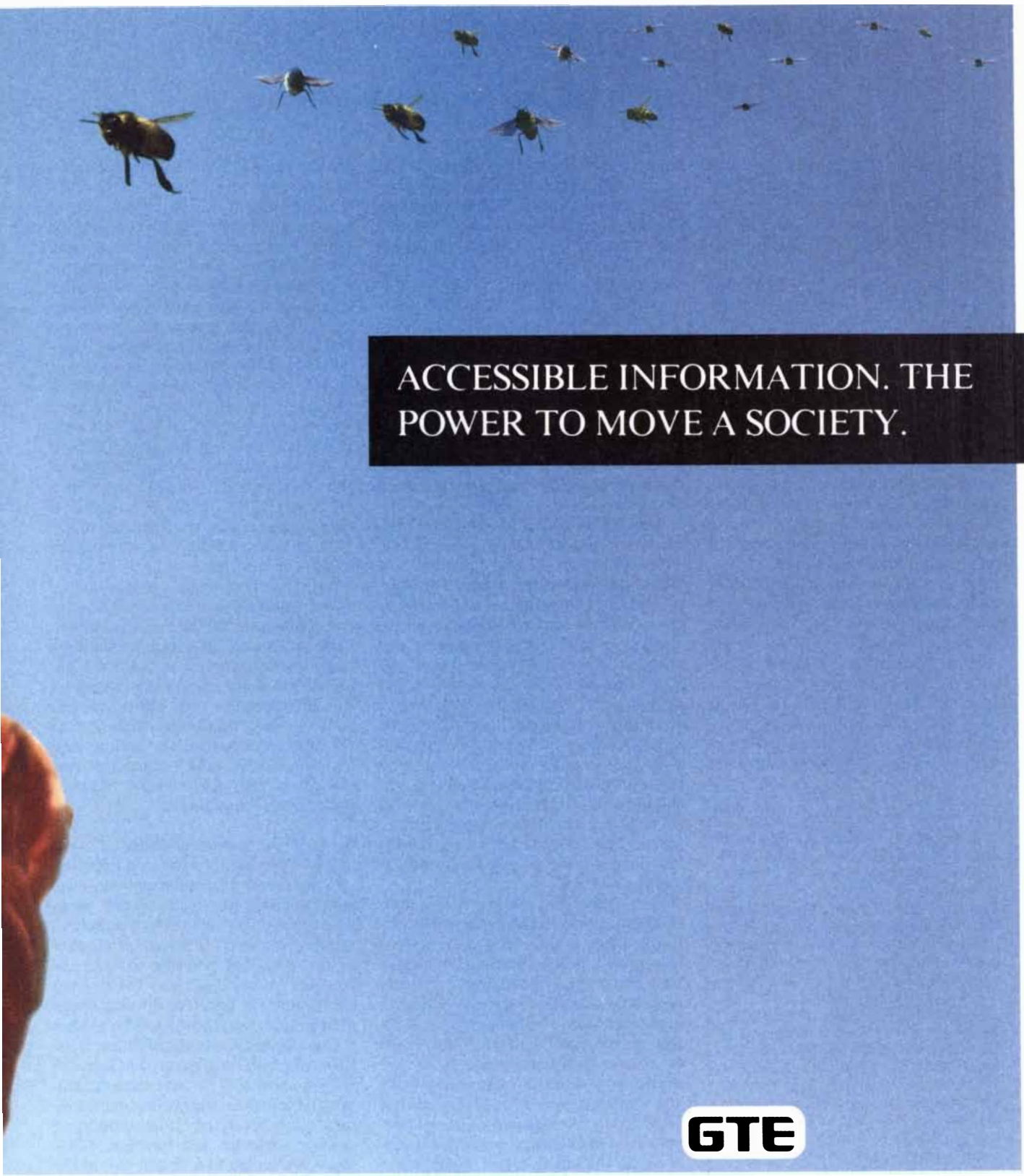


X-ray Microscopes

Recent progress has yielded "soft" X-ray instruments whose resolution is 10 times better than that of optical microscopes. They offer a new way to observe minute structures and to perform chemical analysis

by Malcolm R. Howells, Janos Kirz and David Sayre

Each advance in microscopic technique has provided scientists with new perspectives on the function of living organisms and on the nature of matter itself. The invention of the visible-light microscope late in the 16th century introduced a previously unknown realm of single-cell plants and animals. The development of X-ray crystallography early in the 20th century yielded for the first time accurate images of matter at atomic resolution. During subsequent decades, electron microscopes have provided direct views of viruses and minuscule surface structures. Now another type of microscope, one that utilizes X rays rather than light or electrons, offers a different way of examining tiny details; it should extend human perception still further into the natural world.

The new X-ray microscopes considerably improve on the resolution of optical microscopes. They can also be used to map the distribution of certain chemical elements. Some can form pictures in extremely short times, and some hold the promise of special capabilities such as three-dimensional imaging. Unlike conventional electron microscopy, X-ray microscopy enables specimens to be kept in air and in water, which means that biological samples can be studied under conditions similar to their natural state. The illumination used, so-called soft X rays in the wavelength range of 20 to 40 angstroms (an angstrom is one ten-billionth of a meter), is also sufficiently penetrating to image intact biological cells in many cases. Because of the wavelength of the X rays used, soft X-ray microscopes will never match the highest resolution possible with electron microscopes. Rather their special properties will make possible investigations that will complement those performed with light- and electron-based instruments.

MALCOLM R. HOWELLS, JANOS KIRZ and DAVID SAYRE have collaborated on various X-ray imaging projects associated with the National Synchrotron Light Source at Brookhaven National Laboratory. Howells, who received his Ph.D. in physics at the University of London, is now senior staff scientist at the Advanced Light Source of Lawrence Berkeley Laboratory. Kirz earned a Ph.D. in physics at the University of California, Berkeley. He is professor of physics at the State University of New York at Stony Brook. Sayre received his Ph.D. in chemical crystallography from the University of Oxford and spent many years on the research staff at IBM. He has retired, but he continues to work as a guest investigator at S.U.N.Y.–Stony Brook and at Brookhaven.

The dream of building an X-ray microscope dates to 1895, when Wilhelm Röntgen of the University of Würzburg discovered X rays. The ability of X rays to penetrate solid objects provided strong motivation to use them for microscopy. Scientists quickly discovered, however, that they could not refract or reflect X rays as they could visible light. Instead the first images were made by shining X rays through a specimen placed in contact with ordinary photographic film. The X rays that passed through the specimen exposed the film, and the resulting image could then be examined with a light microscope. This form of X-ray microscopy, known as contact microradiography, is still in use today.

Early in the 20th century, X rays were identified as electromagnetic waves, differing from visible light only in that they have a much shorter wavelength. This discovery implied that X-ray microscopy offered a possible path to high resolution. The wavelength of light sets an ultimate limit of about 2,500 angstroms to the resolution of optical microscopy. Optical microscopes built 100 years ago already approached that limit closely. Biologists recognized that improved resolution was needed to understand the function and organization of cells and reasoned that X rays, with their very short wavelengths, should be able to help.

Unfortunately, the large grain size of photographic film severely constrained contact microradiography. The optical microscope used in examining the exposed film further limited the technique. As a result, early X-ray microscopy could not match, much less exceed, the resolution of existing optical microscopy. What was needed was a system that could make a focused X-ray image. The development of such a system turned out to be a difficult task, which only now is being accomplished.

In 1923 Arthur H. Compton showed that X rays could be efficiently reflected from highly polished surfaces if they impinged at a small grazing angle. With an appropriately shaped surface, X rays could be made to focus and produce magnified images analogous to those achieved by conventional optical systems. In the late 1940s Paul H. Kirkpatrick and his group at Stanford University attempted to build a high-resolution X-ray microscope based on this principle, but their effort failed to achieve resolution better than that of the light microscope. Aberrations and the demanding surface manufacturing tolerances that this scheme required posed severe limitations.

While the performance of X-ray microscopes resisted improvement, a competitor—the electron microscope—made rapid progress. During the 1940s, electron microscopes routinely achieved resolution better than that possible with a visible-light microscope, and the biological community began to develop specimen-preparation techniques to exploit the new instruments' capabilities. Since then, electron microscopy has become the standard tool for an entire generation of biologists, supporting extraordinary advances in the understanding of cellular structure and function. For a while, it also led to a virtual halt in the development of the X-ray microscope.

In the past 20 years interest in X-ray microscopy has revived, largely because of several major technical advances. Most significant of these has been the development of new sources of X-ray illumination. To achieve high-resolution imaging, some types of X-ray microscope need sources of unprecedented brightness. The past decade has seen rapid advances in the brightness of X-ray sources based on synchrotron radiation (radiation emitted by energetic charged particles accelerated by a magnetic field).

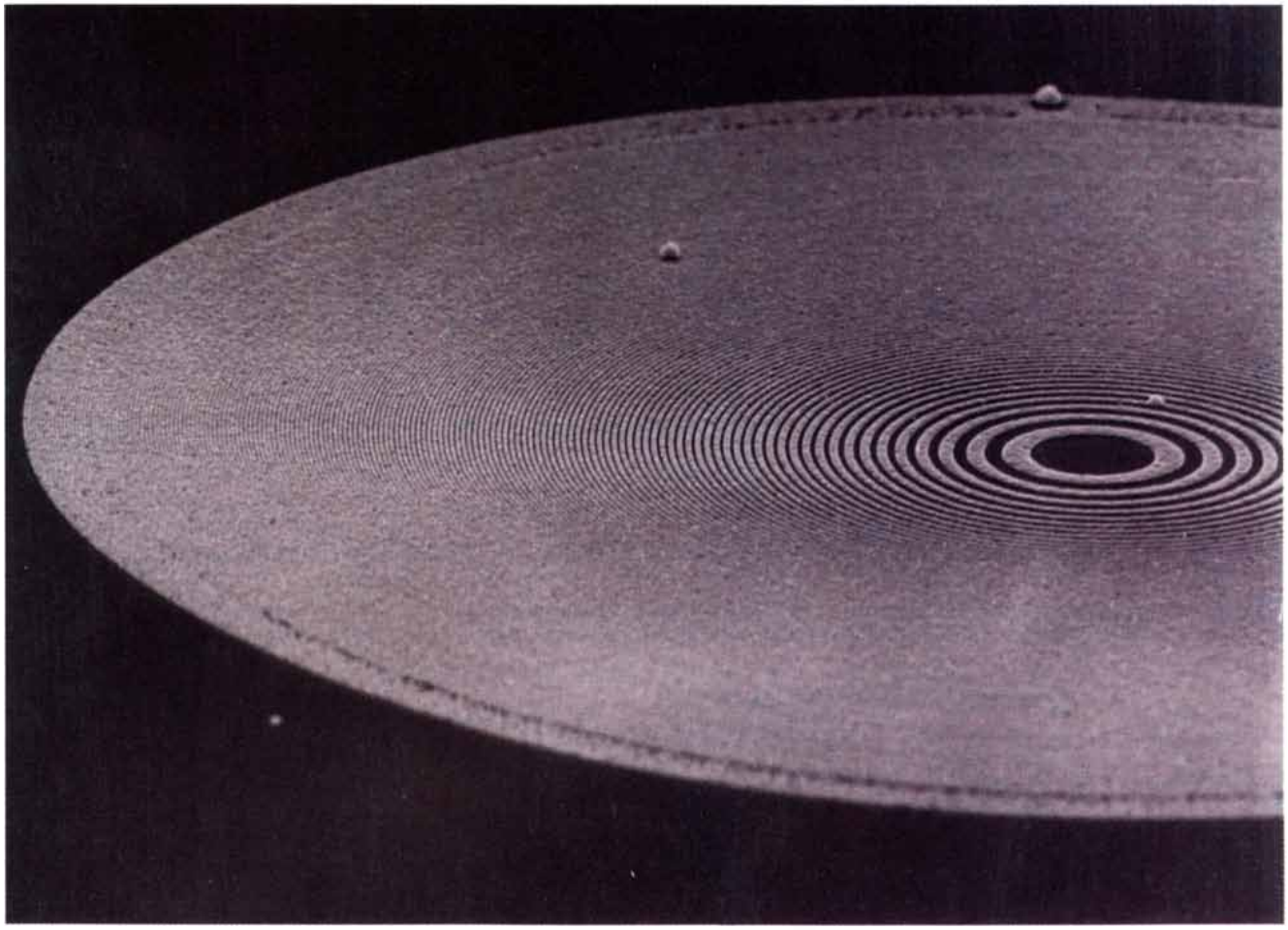
As a result, the brightness available today is millions of times that of the X-ray tubes, which, for most of this century, were the only available sources of soft X rays. Progress has also occurred in the development of X-ray lasers and X ray–emitting plasmas, which can provide enough X rays in a single pulse to form an image in one nanosecond (one billionth of a second) or less.

X-ray detectors have also drastically improved. Electronic detectors have been introduced, and resist material—a thin layer of plastic whose resistance to etching changes when exposed to electrons or X rays—has replaced photographic film in many applications. Resist materials serve as convenient, inexpensive X-ray detectors, and their resolution is almost 100 times better than that of photographic film.

Another important advance is that researchers have finally succeeded in focusing X rays with suboptical precision by using a device known as a Fresnel zone plate. Zone plates are circular gratings that consist of alternating transparent and opaque rings whose spacing diminishes with distance from the center. Waves are diffracted as they pass through the transparent rings. In this manner, each part of the incoming beam is deflected so that all the waves unite at a common focal point. Zone-plate lenses have been used to focus light, radio waves, sound and even neutrons. In 1960 Albert V. Baez, then at the Harvard-Smithsonian Astrophysical Observatory, proposed that such plates could focus X rays as well.

Making high-resolution zone plates is technically demanding. The best resolution possible with a given plate is roughly equal to the size of its finest zone spacing. Achieving resolution better than that of an optical microscope therefore necessitates creating zones whose spacings are much smaller than the wavelength of light. Standard optical fabrication techniques are certainly not up to this task. Nevertheless, by applying methods developed for the manufacture of microcircuits, researchers have recently built zone plates with spacings as fine as 300 angstroms, about one twentieth the wavelength of visible light.

One approach, pioneered by Günter Schmahl and Dietbert Rudolph of the University of Göttingen, uses ultraviolet holographic techniques (an extension of those used to make familiar visible-light holograms) to imprint a zone-plate pattern into a layer of resist. The holographic method has resulted in some impressive successes, but it is subject to a fundamental diffraction limit of ap-

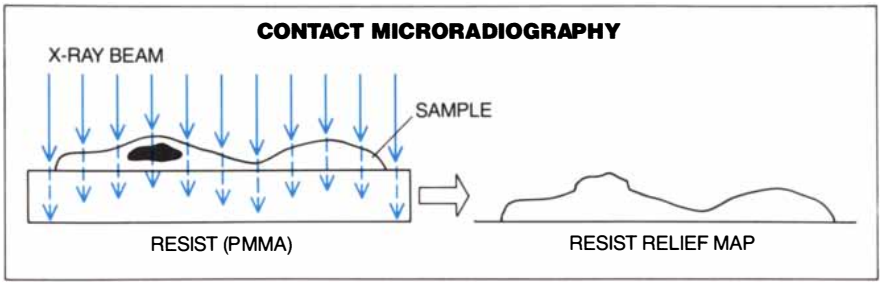


FRESNEL ZONE PLATE consists of nested gold rings supported on a silicon nitride membrane only 1,200 angstroms thick. X rays passing through the zones between the rings are diffracted and brought to a focus. In this way, one can build X-ray lenses analogous to those used in visible-light microscopes. The width of the finest zones (which roughly equals the best resolution obtainable in a microscope using the plate) is 300 angstroms. The plate was fabricated by Erik Anderson.

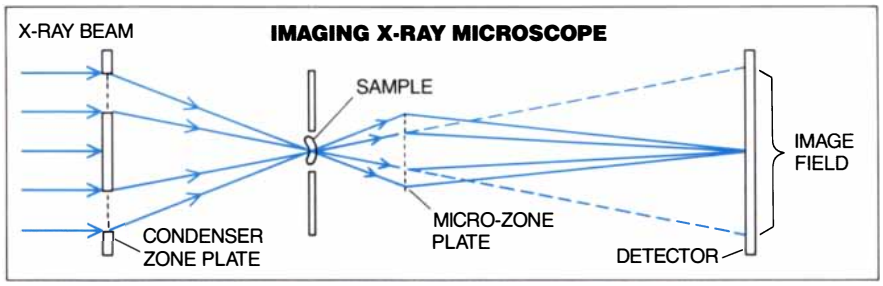
proximately 500-angstrom zone widths.

Another, even more precise technique directs beams of electrons to "write" the zone-plate pattern into resists. Microfabrication methods make it possible to transform resist patterns into gold, nickel or germanium structures. The electron-beam technique was first demonstrated in 1974 at the IBM Thomas J. Watson Research Center, where the finest available zone plates continue to be made in Dieter Kern's laboratory (where they are currently being made by Erik Anderson of Lawrence Berkeley Laboratory's Center for X-ray Optics, under the direction of David Attwood). All the scanning X-ray micrographs shown in this article were taken using zone plates produced by this collaboration. Pambos Charalambous, working in Ronald Burge's group at King's College in London, has also made precision zone plates by means of a related technique. The highest-resolution zone plates so far manufactured have outer-zone widths in the 200- to 300-angstrom range.

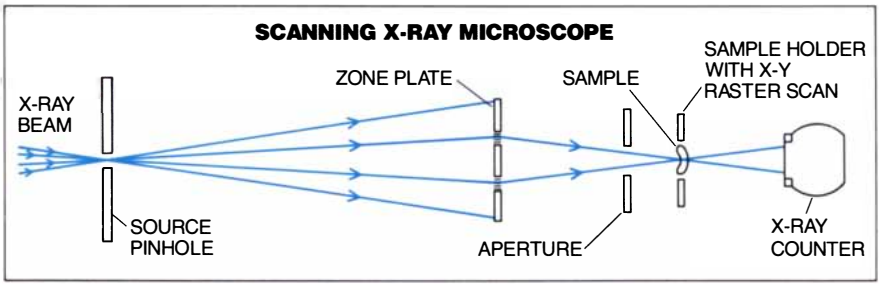
Zone plates for X rays are quite small, about 0.1 millimeter in diameter. They are also necessarily thin, so they work best with X rays having wavelengths longer than about five angstroms.



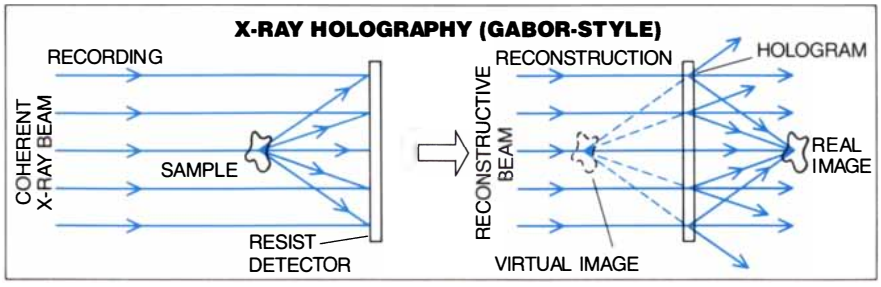
DAMAGE PATTERN in the resist results from the X rays that pass through the sample (*left*). A developer preferentially dissolves the radiation-damaged regions (*right*).



FRESNEL ZONE PLATES serve as condenser and objective X-ray lenses. The former focus a beam on a sample; the latter magnify images of the sample on a detector.



FOCUSED X-RAY BEAM scans back and forth, top to bottom across the sample; the rays that penetrate at each point are measured using a proportional X-ray counter.



INTERFERING incident and scattered X-ray beams record a hologram in a sheet of resist (*left*). The image is reconstructed (*right*) either by illuminating the hologram with laser light or by digitizing the hologram and performing a computation on it.

Within the past few years, technical advances have enabled X-ray microscopes to achieve resolutions beyond the limit of the optical microscope. So far four X-ray methods have achieved this feat: contact microscopy, imaging microscopy, scanning microscopy and holography. Each has its own advantages.

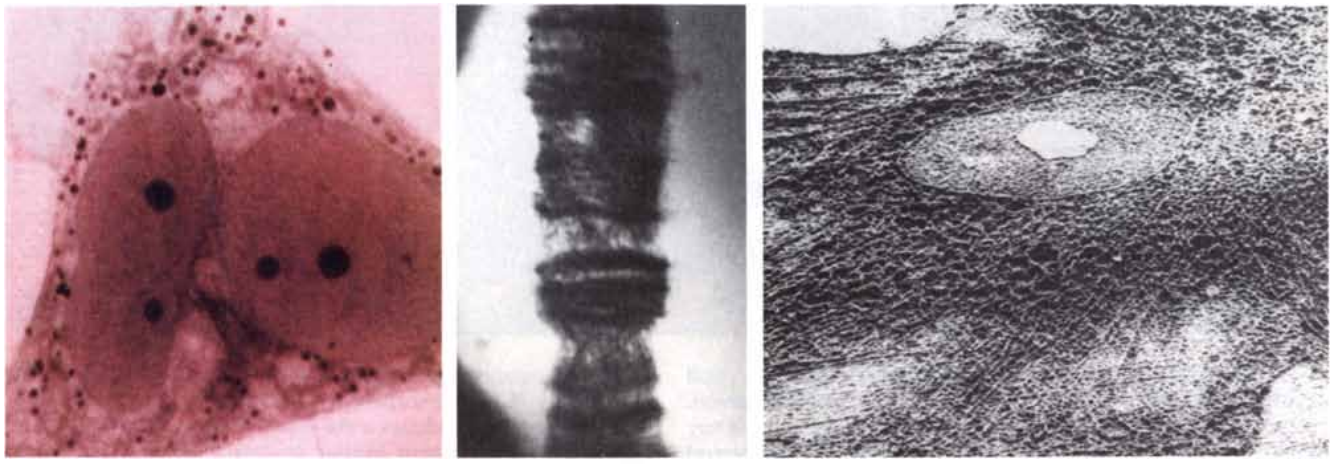
Contact microscopy is the most widely exploited technique. Modern contact microscopy differs from earlier contact microradiography in two main ways. Resist materials (often PMMA, the material used to make Plexiglas) permit resolution superior to that of the photographic films originally used, and higher-resolution instruments, principally the electron microscope, are now available to view the image recorded in the resist. Both advances derive from a 1956 paper by William A. Ladd and his co-workers at the Columbian Carbon Company in New York.

Microscopy using resist detectors was pioneered by Ralph Feder and Eberhard Spiller of IBM. Although the contact method possesses many advantages, including relative simplicity and convenience, the resolution of contact images is limited by the fidelity of available readout procedures and by diffraction blurring, a problem for thicker specimens.

The imaging X-ray microscope uses focusing optics to form an image magnified a few hundred times, which can then be recorded by a detector of modest resolution. The highest-resolution devices currently employ a Fresnel zone-plate lens as the focusing element. The recording device can be X ray–sensitive photographic film or an electronic detector. Schmahl's group in Göttingen has built a microscope of this type that achieves resolutions of about 550 angstroms using the holographically created zone plates of the kind referred to earlier. Other imaging microscopes are under construction in England and Japan.

SUBOPTICAL IMAGES PRODUCED USING THREE DIFFERENT X-RAY MICROSCOPIC TECHNIQUES

SCANNING MICROSCOPE | IMAGING MICROSCOPE | CONTACT MICRORADIOGRAPHY



CONNECTIVE TISSUE CELL in a chick embryo (*left*) was imaged by John Gilbert, Jerome Pine and Christopher Buckley using the scanning X-ray microscope at Brookhaven. Two nuclei, each containing two nucleoli, are visible, as are numerous granules too small to be seen by a light microscope. The cell was fixed but wet and unstained. Using the Göttingen imaging X-ray microscope at the BESSY storage ring, Peter Guttman and his collaborators produced a view of the filamentary structure of a wet, unstained chromosome from a midge larva (*center*). Contact microscopy done by P. C. Cheng and O. C. Wells yielded an image of a fixed, dried human connective tissue cell (*right*), which shows stress fibers outside the cell's nucleus. The image depicts the surface of the X-ray resist as magnified by an electron microscope.

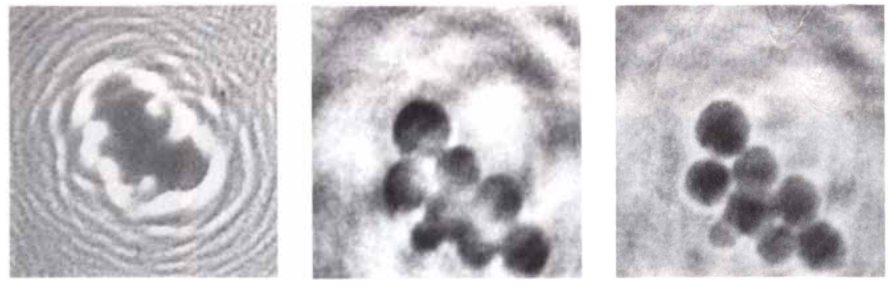
Imaging X-ray microscopes offer many benefits. The chief one is that the entire sample is illuminated and imaged at once. This permits rapid picture taking, which helps to combat blurred images resulting from motion and minimizes radiation damage in biological samples. It also avoids the need for advanced X-ray sources with a great degree of coherence, or phase organization. In addition, because these microscopes have no moving parts, they should be very reliable. For these reasons, imaging X-ray microscopes are amenable to commercial design. A consortium of the universities of Göttingen and Aachen, along with the Carl Zeiss Optical Company, is currently developing an instrument of this kind [*see illustration on page 94*].

Recently the Göttingen group showed how to produce an image whose gray level is proportional to the X-ray phase change induced by transmission through the specimen. Such "phase contrast" imaging will eventually allow greater flexibility in wavelength, lower X-ray doses and perhaps even higher resolution.

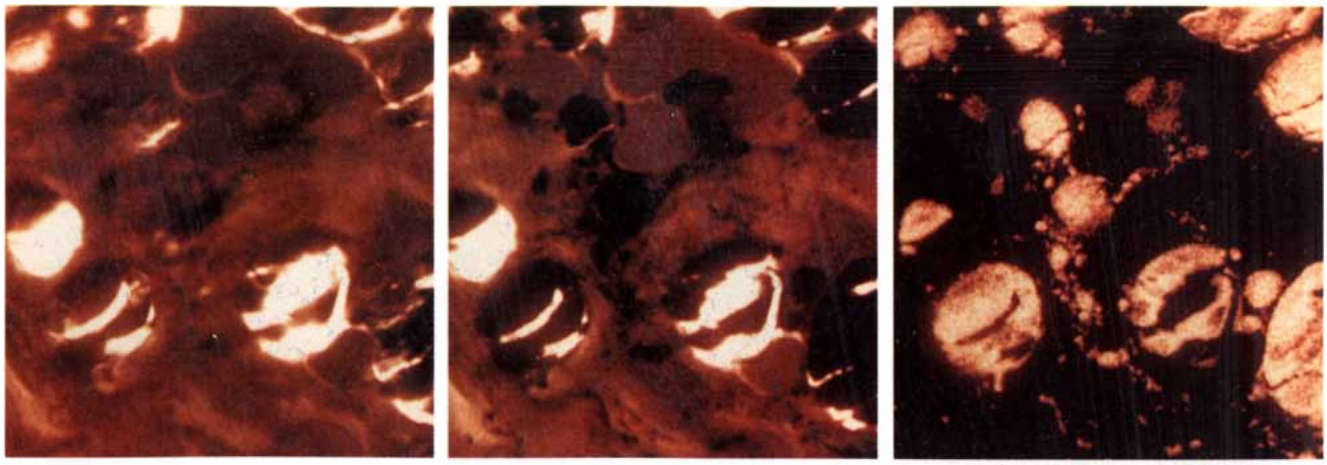
For years, contact and imaging X-ray microscopes were well ahead of other designs in terms of the number of X-ray micrographs produced. That situation is changing, however, because of the successful commissioning of several new scanning X-ray microscopes. In scanning microscopes the image is built up one picture element (pixel) at a time, much like the picture on a television screen. The process begins by using a zone plate to focus an X-ray beam to a fine point that illuminates a single spot on a specimen. Some of the rays penetrate the specimen, and the fraction of the incident beam that passes through determines the gray value assigned to that pixel. The focused spot scans across the specimen in lines from side to side and top to bottom, recording successive pixels. The spot size determines the resolution.

Although seemingly slow and laborious, the scanning method has distinct advantages. The technique lends itself readily to computer-based image recording and pixel-by-pixel chemical analysis. Moreover, it conveniently allows the sample to remain in air, whereas nearly all of the X-ray beam path lies in a vacuum. Scanning also minimizes the exposure of the specimen to damaging radiation. When implemented with a Fresnel zone plate, however, this method requires a coherent soft X-ray beam, which can be supplied only by a major synchrotron radiation facility.

The first scanning X-ray microscope to reach suboptical resolution was built in 1982 by one of us (Kirz), Harvey Rarback and John Kenney of the State University of New York at Stony Brook. It is located at the National Synchrotron Light Source (NSLS) of Brookhaven National Laboratory. Researchers recently rebuilt this microscope to improve its resolution and to increase its picture speed so as to exploit a new "undulator" X-ray source. This device magnetically steers electrons in a gently undulating path, which causes them to emit a narrow X-ray beam of extraordinary



X-RAY HOLOGRAM (*left*) provides the information to form the two reconstructed images of a clump of dried enzyme-storage vesicles. One image exhibits amplitude contrast (*center*); the other, phase contrast (*right*). The hologram was made at the X1 X-ray undulator beam line at Brookhaven by Chris Jacobsen, Howells and Rothman.



DISEASED HUMAN TENDON was studied by Buckley and Yusuf Ali with the scanning X-ray microscope at Brookhaven. Images of unstained sections of tendon were taken at X-ray energies just below (*left*) and just above (*center*) 350 electron volts, the energy threshhold at which calcium suddenly increases its X-ray absorptivity. Subtracting the first image from the second produces a difference image (*right*), in which lighter tones represent higher concentrations of calcium.

brightness. With such a beam, the microscope can now produce a picture in about a minute. The upgrade was done by a larger group, including Christopher Buckley, Mark Rivers and Deming Shu and others from Stony Brook, the NSLS and the Center for X-ray Optics. A similar microscope built by the King's College group operates at the Daresbury Laboratory in Cheshire; several others are under construction.

One of the leading goals of X-ray microscopy has been to examine biological material in something close to its natural state. This goal requires that specimens be intact and, therefore, thick and three-dimensional. In the examination of such objects, it is appropriate to use soft X rays because they have approximately the right penetrating power. Researchers are interested in the possibility of employing X-ray holography, a relative of the holographic method used in making zone plates, to image such samples in three dimensions.

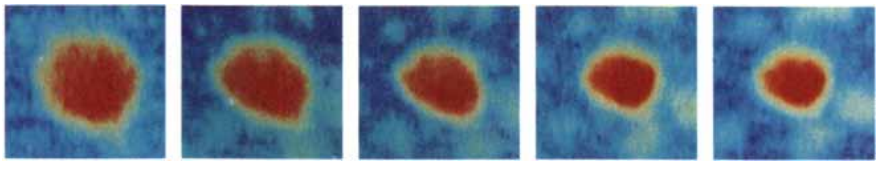
Three-dimensional X-ray holography demands better resolution than is now possible. Nevertheless, microscopists recently have acquired detailed two-dimensional holographic images. Holography has the added feature that, like contact microscopy, it does not require a focusing mechanism.

Holographic imaging, first proposed in 1948 by Dennis Gabor of the British Thomson-Houston Company, depends on the fact that light and other forms of radiation consist of waves that interact much like water waves. When two waves are combined, in certain places the wave crests coincide (reinforcing each other), whereas in others a crest coincides with a valley (canceling each other). The net result is that a pattern of maxima and minima forms when a wave that has been scattered by a sample is combined with the original illuminating beam. Gabor called the recording of this pattern a hologram. A hologram stores information on both the amplitude and phase of the scattered wave, providing enough data to reconstruct an image of the sample.

In 1952 Baez proposed a scheme for a lensless holographic microscope using X rays. His design was conceptually simple but technically formidable. Neither the intensity of the coherent X-ray sources nor the resolution of the available photographic emulsions was up to the task. These technological limits have recently been overcome. Within the past couple of years, Dennis Joyeux in France, Sadao Aoki in Japan and James Trebes and Ian McNulty in the U.S., along with their respective collaborators, have all produced high-resolution X-ray holograms.

In 1987 one of us (Howells) and Chris Jacobsen, working with Kirz and Stephen S. Rothman of the University of California at San Francisco and of Lawrence Berkeley Laboratory, demonstrated the first holographic microscope whose resolution was superior to that of the optical microscope. We used an undulator X-ray source and high-resolution resist detectors, which initially produced holograms after a one-hour X-ray exposure and yielded an overall image resolution of better than 1,000 angstroms.

Recent work has reduced exposure times to one minute and improved the resolution to 600 angstroms. This resolution is still inadequate for making three-dimensional images. If, as we hope, the resolution of the present experiments can be pushed closer to the intrinsic resolution of the resist (about 100 angstroms for PMMA), then three-dimensional images should become possible.



ENZYME STORAGE VESICLE in a pancreatic cell changes in size and density as it releases its protein content. This sequence of images, produced by Kaaren Goncz and Stephen S. Rothman working on the scanning X-ray microscope at Brookhaven, provides a quantitative measure of these changes over approximately three hours.

Now that X-ray microscopes are a practical reality, attention is being devoted to their most fruitful applications. Workers have already used X-ray microscopes to examine a wide variety of samples, from earthworms contaminated with heavy metals to human cancer cells and from foxglove epidermal hairs to coals, semiconductor devices and curing cement. Much current research centers on exploring the capabilities of the microscopes and their applicability to different kinds of samples. Given the short history of high-resolution X-ray micros-

copy, one needs to be cautious in judging which applications can (or cannot) benefit from it.

Results from the current X-ray devices have confirmed that, as expected, X-ray images and electron micrographs of the same sample do not normally look alike. X-ray microscopes are sensitive to the concentration of specific chosen elements, often carbon and nitrogen, whereas electron microscopes normally map the distribution of the chemical groups in the sample that bind with a contrast-producing stain. Neither picture is wrong. They simply describe two different aspects of the sample's structure.

In general, X-ray and electron microscopies have complementary advantages. Electron microscopes long ago surpassed the resolution of the optical microscope and, for many samples, can now provide resolutions between two to 20 angstroms. The resolution of current X-ray microscopes, on the other hand, is of the order of a few hundred angstroms, and the fundamental diffraction limit (half the X-ray wavelength) constrains the amount of improvement possible. Microscopes that use the soft X rays considered in this article will never attain resolutions better than between 10 and 20 angstroms.

The main contribution of X-ray microscopes will not be the breaking of frontiers in resolution but rather the ability to make quantitative measurements of biological objects with little or no modification, in conditions very close to their natural state. Such specimens can be studied by conventional electron microscopy only after considerable chemical or physical alteration. In some cases, the effect of preparation and radiation in X-ray imaging seems sufficiently mild that the specimen remains able to respond to certain applied stimuli. For these specimens, one can take a sequence of pictures that enable the responses to be both studied and distinguished from the effects of the X-ray illuminating beam.

An especially significant feature of X-ray microscopes is that they can highlight or suppress the visibility of a particular element present in the specimen. Every element absorbs X rays in a distinctive manner. At X-ray wavelengths between 23 and 44 angstroms, oxygen—and therefore water—is much more transparent to radiation than is organic material. This fact opens up the possibility of discerning features through water, which makes up about three quarters of the mass of most cells. This part of the X-ray spectrum, called the water window, is quite useful for biological microscopy.

The way in which X rays interact with matter permits X-ray microscopes to perform detailed, quantitative measurements of the density and chemical composition of a sample. For each element, there exist certain, critical X-ray energies, known as absorption edges, at which X rays possess just enough energy to unbind and free an electron. Only X rays having at least the critical energy are efficiently absorbed by that element. One can exploit this property by making images at X-ray energies just below and above an absorption edge. Subtracting the former from the latter essentially erases the signal of all elements except the one that has an edge at that energy. In this way, X-ray microscopes can map the distribution of a single element in a sample.

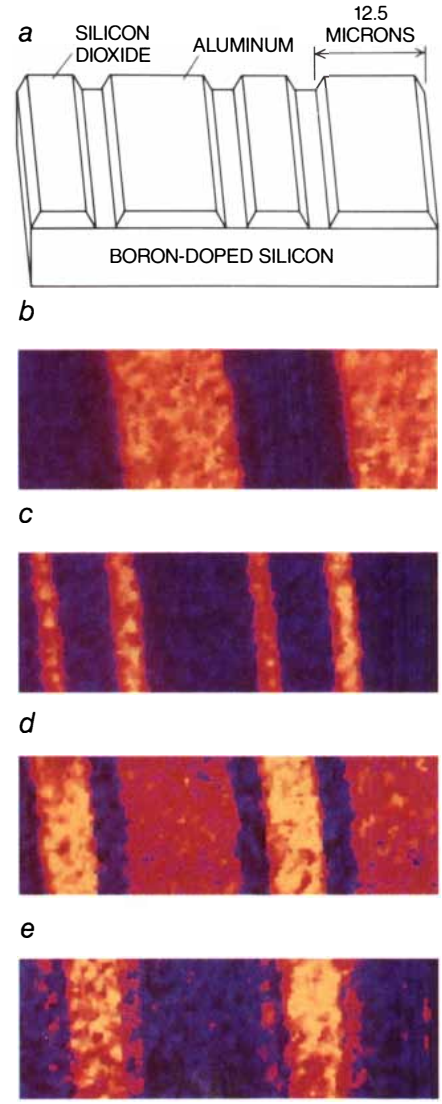
The problem of radiation damage limits the useful applications of both electron and X-ray microscopes. Radiation-induced changes can be biologically significant even if they affect only a small proportion of the molecules in the cell. Therefore, suboptical resolution imaging of initially living cells formed by means of any ionizing radiation always generates significant biological effects.

As microscopists, our view of radiation damage differs from that of radiation biologists. We want to know the extent of harm to the *image* at a given resolution in the context of what we had hoped to learn. Radiation biologists, on the other hand, are primarily concerned with the degree of harm done to the *organism* and its various systems (for example, reproduction). Either way, understanding the interaction between probing radiation and samples is a complex matter. Experimental studies of the damage caused by soft X rays, in terms of their effects on microscopic images, are at a very early stage.

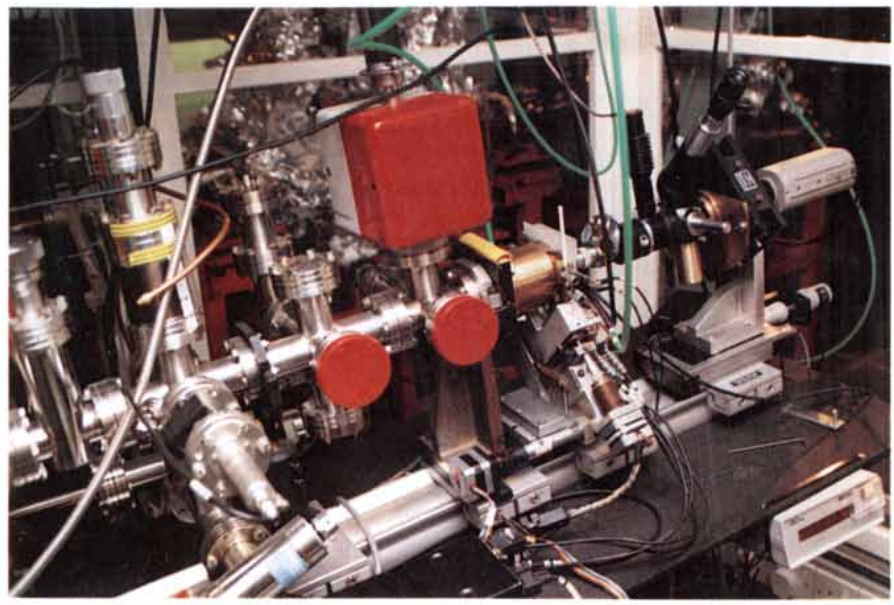
With techniques such as the exploitation of absorption edges, X-ray images can achieve superior contrast (signal-to-noise ratio), and, unlike their electron counterparts, they are not disturbed by certain background effects, such as multiple electron scattering. The cleaner signal obtainable with X-ray methods enables a given microscopic imaging task to be done with less damage than is possible when using imaging methods based on electrons or other charged particles. X rays are also compatible with very rapid (flash) imaging, and this provides another way to minimize the effects of radiation damage.

These advantages, coupled with the modest resolution goals of X-ray microscopy relative to electron microscopy, enable X rays to be used for studies of unprotected, natural biological material. In many cases, X-ray microscopes can yield images that are not degraded by radiation damage and that still have resolution far beyond that attainable with the optical microscope.

What does the future hold for X-ray microscopy? Perhaps the most basic development will be the expected improvement in performance, especially



CHEMICAL COMPOSITION of a microfabricated sample (*a*) was studied by Harald Ade and co-workers using a scanning photoelectron microscope, in which X rays eject electrons from atoms near the sample's surface. Selecting characteristic electron energies associated with aluminum (*b*), silicon (*c*) and oxygen (*d*) identified and mapped each element in turn. Silicon atoms bound in silicon dioxide molecules (*e*) showed up at an energy that was chemically shifted from the pure silicon level. In this way, two different chemical states of silicon have thus been distinguished.



COMPACT IMAGING MICROSCOPE (*left*) developed at the universities of Göttingen and Aachen incorporates a plasma X-ray source; it has demonstrated a resolution of 1,000 to 2,000 angstroms. Scanning X-ray microscope (*right*) operated by King's College in London sits on the undulator beam line at the Daresbury synchrotron light source in Cheshire.

in resolution. The X-ray microscopes described here can image features as small as 200 to 1,000 angstroms. They are all limited, however, by their dependence on the properties of resist materials, which are involved directly in holographic and contact imaging or indirectly in the manufacture of the zone plates that are used in other X-ray microscopes. The intrinsic limit to the resolution of PMMA , approximately 100 angstroms, is fundamentally determined by its molecular size, and so surpassing this resolution limit will require new approaches.

Phase contrast X-ray microscopy, only recently realized in practice, promises to be a powerful technique that should provide improved contrast and lower radiation doses in the shorter-wavelength X-ray range. New synchrotron radiation sources, such as the Advanced Light Source now under construction at the Lawrence Berkeley Laboratory, will increase the available brightness of sources, permitting much more rapid imaging.

Better resolution without the limits imposed by PMMA also may soon be possible. Suppose, for example, that the X-ray diffraction pattern were measured without the use of a reference wave, as is done in X-ray crystallography. The overall pattern of intensity of the beams in such experiments should allow researchers to deduce the structure of the object that scattered the X rays. The fineness of resolution obtainable by this method is determined by the range of angles over which the diffracted rays can be measured. The ultimate case, collection over an entire sphere (which can be realized in crystallography), would permit full three-dimensional imaging and a resolution equal to half the wavelength of the X rays used. For the X rays considered here, that translates into a resolution of 10 to 20 angstroms.

Recent experiments initiated by one of us, Sayre, along with Kirz, WenBing Yun of Argonne National Laboratory and Mark Sharnoff of the University of Delaware, have already recorded X-ray diffraction patterns out to an angle of 15 degrees with respect to the incident beam, corresponding to an imaging resolution of 70 angstroms. This value may improve further when plans for a more rigorously coherent X-ray beam are implemented.

X-ray microscopy has already begun to branch out beyond the life sciences toward surface science and trace element analysis. For surface science, one studies not the X rays but electrons ejected from atoms near the sample surface by the rays. The technique for measuring the energy of the freed electrons, known as photoelectron spectroscopy, is well established. Combining spectroscopy with high-resolution X-ray imaging will make it possible to identify and map the elemental distributions and chemical bonding states near the surface of the sample.

These advances will open up areas of investigation of heterogeneous surfaces, such as those of catalysts and semiconductor devices. Recently Harald Ade, with Erik Johnson and Steven L. Hulbert from the NSLS and with Anderson, Kern and Kirz, achieved submicron resolution. He and his colleagues also were able to study the chemistry in all the above ways with a zone plate–based photoelectron microscope at the NSLS. Other, similar devices are under development at Hamburg, Stanford, Wisconsin and elsewhere around the world.

After almost a century of research, the technologies of the microfabrication era have finally brought the X-ray microscope from dream to reality. The X-ray studies now within reach represent a valuable opportunity to extend human understanding of the natural world. We are optimistic that progress will continue and that the promise of these instruments will be fulfilled.

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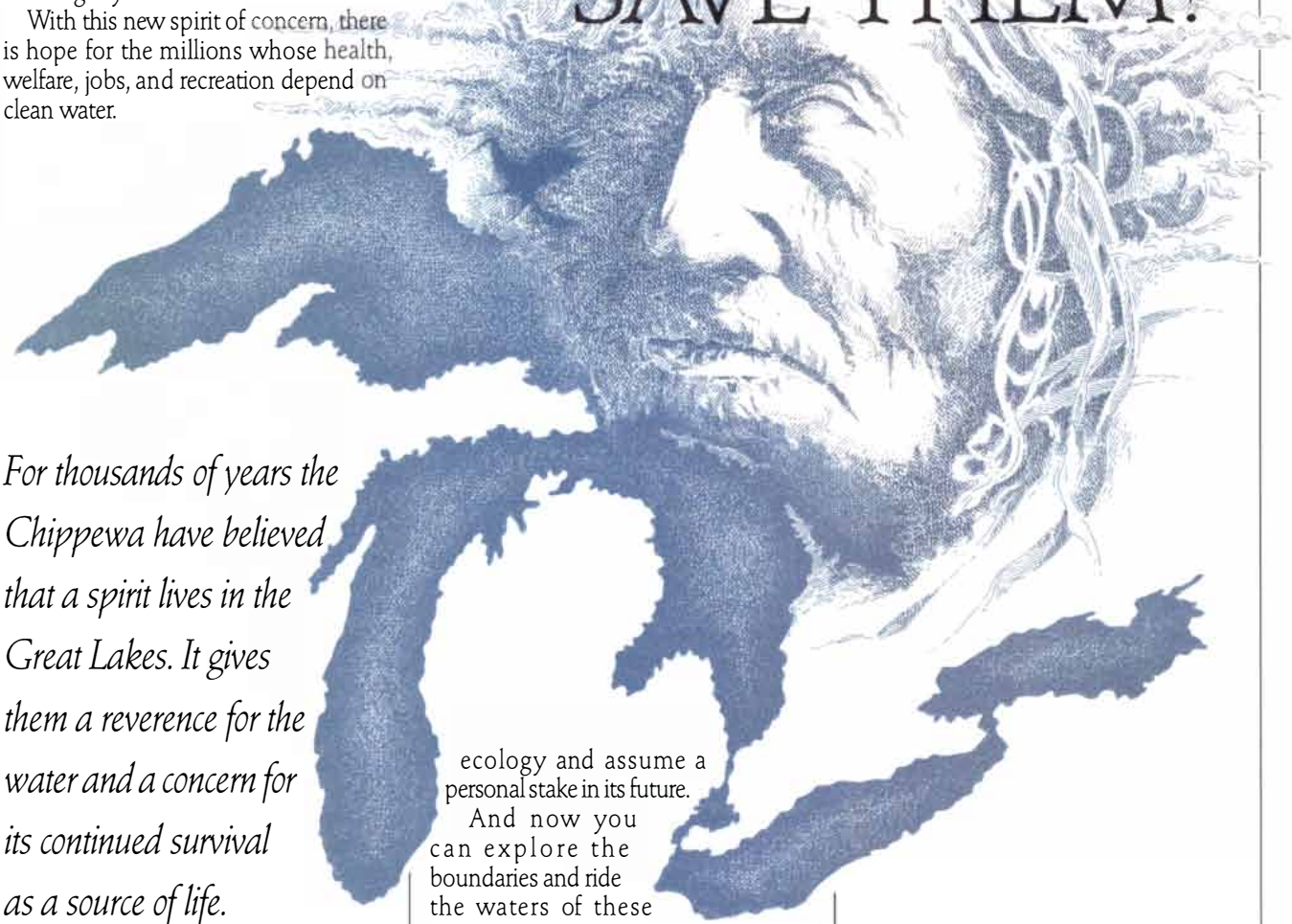
RESTORING AMERICA'S INLAND SEAS

HAS THE SPIRIT OF THE LAKES COME BACK TO SAVE THEM?

HUMAN ABUSE for 300 years has gravely injured the Great Lakes. Soil erosion from deforestation, pollution from industrial waste, urban sewage, and invader species have all played havoc with the ecosystem of the once "sweet seas."

To save the lakes, the United States and Canadian governments, as well as research institutes, businesses, citizens' groups, and private individuals banded together in a spirit of restoring the waters to their former glory.

With this new spirit of concern, there is hope for the millions whose health, welfare, jobs, and recreation depend on clean water.



For thousands of years the Chippewa have believed that a spirit lives in the Great Lakes. It gives them a reverence for the water and a concern for its continued survival as a source of life. Perhaps this spirit now guides all those who are working in the Great Lakes basin to keep the lakes alive.

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The Echidna

This egg-laying mammal, also called the spiny anteater, has lived in relative obscurity in the Australian bush. Now secrets of its natural history and reproductive behavior are being explored

by Peggy D. Rismiller and Roger S. Seymour

The echidna is the most widely distributed and at the same time perhaps the most mysterious native Australian animal. Seldom seen on the island continent, the echidna (pronounced "ee-kid´-na") is virtually unknown in the rest of the world, unlike its nearest relative, the platypus. Although scientists have been studying the echidna for nearly 200 years, there are large gaps in this egg-laying mammal's recorded natural history. Much of the information passed on as lore is based on incomplete facts.

Recently, however, continuous field observations of the everyday activities and seasonal habits of echidnas have greatly contributed to our understanding of their biology. In particular, we have started to elucidate their reproductive behavior. This work, in conjunction with historical data, laboratory studies and other observations made by us and our colleagues, has clarified aspects of the mating process, the gestation period and the early development of the hatchling.

Only by fully understanding the biology of the echidna can we begin to assess the dangers posed by human encroachment on its habitat. Even given the findings of our recent research, we still do not know enough about the echidna to be able to protect it and its environment so that it does not become endangered.

PEGGY D. RISMILLER and ROGER S. SEYMOUR share an interest in monotreme biology. Rismiller is an environmental physiologist who is living and working with her research animals on Kangaroo Island, South Australia. She received her Ph.D. from Philipps University in Marburg, Germany. Rismiller's special area of research includes circadian rhythms, particularly body temperature regulation, metabolism, hibernation and reproductive activity. Seymour received his Ph.D. from the University of California, Los Angeles, and is a physiologist at the University of Adelaide in Australia. His interests include blood gas transport and egg physiology.

In 1792, when George Shaw of the Royal Zoological Society in London received the first echidna for scientific description, he was perplexed. The presence of both spines and hair on the animal made him speculate at first that it represented a new genus of porcupine. The only information accompanying the spiny, stout, beaked creature was "captured in New Holland on an anthill." Because of this detail and the animal's obvious characteristics—naked, elongated snout and long, cylindrical tongue—he mistakenly related the echidna to the South American ant bear (*Myrmecophaga*).

Ten years later Sir Everard Home, a British anatomist, recognized significant anatomical similarities between the echidna and the platypus, thereby establishing their relationship. He found the echidna had a urogenital sinus, a cavity uncommon in mammals, into which all the internal organs empty. Both the echidna and platypus have only one opening from the urogenital sinus for the passage of intestinal, urinary and reproductive products. It is called the cloaca. Because of this shared structure, the echidna and platypus were grouped together under the order Monotremata, meaning "one hole."

There are three living genera of monotremes: the short-beaked echidna (*Tachyglossus aculeatus*), the long-beaked echidna (*Zaglossus bruijni*) and the platypus (*Ornithorhynchus anatinus*). Today there is only one species of long-beaked echidna, which is found solely in New Guinea, and one species of platypus, which has a natural distribution along the eastern coast of Australia and Tasmania.

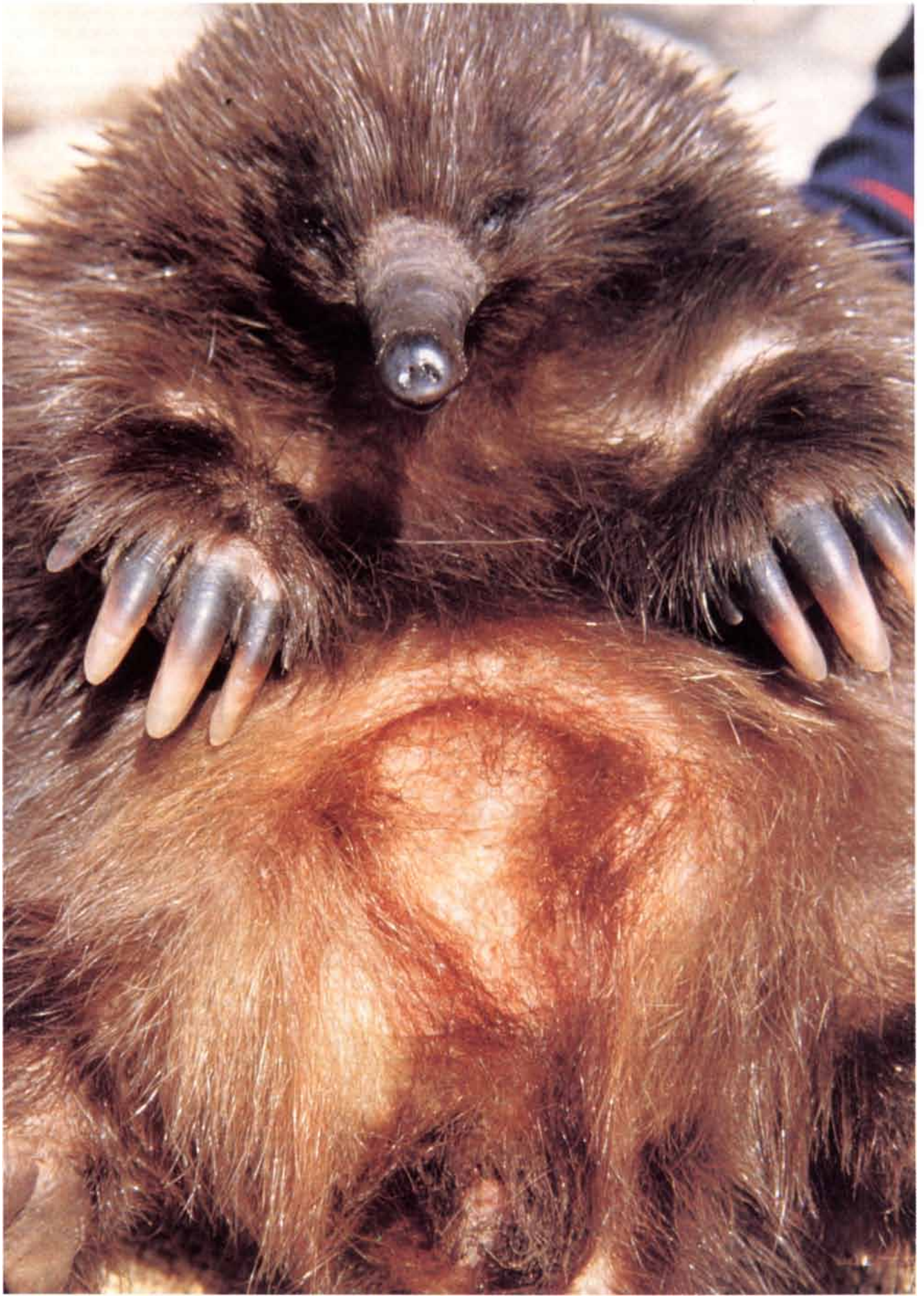
In contrast, short-beaked echidnas are found throughout Australia. The six subspecies are classified by the length of their spines, their hairiness and the relative length of the third hind claw as compared with the second. Echidnas use their elongated hind claws for grooming. Their dexterous hind limbs allow them to reach selectively between the sharp dorsal spines or onto the furry belly.

In addition to the urogenital sinus, the echidna and the platypus share a reproductive anomaly that sets them apart from all other mammals: they lay eggs. Although the Australian aboriginals and possibly a few early colonists were aware of this phenomenon, scientists remained skeptical about this fact for 92 years after they first started studying echidnas.

Sir Richard Owen, another British anatomist, was a firm believer that monotremes were ovoviviparous (meaning that they carried the egg in the uterus until birth). In 1864 he received a letter from an Australian doctor stating that a captive platypus had laid two eggs, but the news did not challenge his assumption: Owen believed that the animal aborted the eggs because of stress. His theory of ovoviviparity persisted for another 20 years.

In 1884 J. Wilhelm Haacke, director of the South Australian Museum in Adelaide, decided to take a closer look at the echidna. Despite the difficulty of obtaining such animals, a pair was sent to him from Kangaroo Island—a small island off the southern coast of Australia. Several weeks after they arrived, Haacke noted that the female had a well-developed pouch. He examined her, hoping to discover a young echidna, but much to his surprise he retrieved a small, round egg from within the longitudinal folds of the belly. Haacke was so fascinated by the rubbery, reptilelike egg that his squeezing caused it to rupture.

ECHIDNA POUCH is formed by the swollen mammary glands and the longitudinal muscles on the belly side of the animal. Because this female is relaxed, the interior of her pouch can be seen.



YEARLING as it forages for ants is covered with soil, which is ingested along with the insect prey. Echidnas are weaned when they are seven or eight months old.

Simultaneous with Haacke's discovery, Scottish naturalist William H. Caldwell found an egg in the pouch of an echidna collected for him by aboriginals. Soon after, he acquired a platypus with a freshly laid egg. Immediately he sent off his famous telegram "Monotremes oviparous, ovum meroblastic," which was read at the British Association in Montreal on September 2 of that year. (Roughly translated, the telegram stated that monotremes lay eggs and that the ova undergo only partial division—similar to embryological development in birds and reptiles.)

News of oviparous mammals caused an uproar in the scientific community. It also gave rise to daring theories that humans evolved from reptiles. After all, monotremes represented a weird mélange of reptilian and mammalian traits. Even though most unfounded hypotheses were quickly discounted, the debate on the origin of monotremes still rages today—partly because very few fossils have been discovered.

Many zoologists support the idea introduced by biologist William K. Gregory in 1947 that monotremes and marsupials are phylogenetically close, evolving from the same ancestor, probably ancient marsupials. A second popular theory holds that monotremes are the last survivors of a noneutherian (animals without a placenta) group of early mammals, originating some 150 million years ago. This view assumes that monotremes evolved independently of all other existing mammals.

Caldwell's telegram prompted the first detailed field investigations of the reproductive habits of monotremes. In 1891, intrigued by the reports of an egg-laying mammal, German biologist Richard W. Semon traveled to Australia to learn more about the echidna. His first task—finding the animals in the unfamiliar Australian terrain—was hardly simple.

The echidna leads a cryptic, usually solitary life. It is active either during the day or at night, depending on season and habitat. To the trained ear, the scuffling of an echidna in the underbrush is distinguishable from that of most birds and small marsupials. But the echidna ceases all activity on hearing or sensing the approach of an intruder. The animal becomes motionless, indistinguishable from its surroundings. We have observed a wallaby bounding past a foraging echidna, without the echidna moving a quill. Kangaroos have also approached or nudged echidnas, only to be totally ignored.

An echidna's whereabouts can usually be determined from its feeding and excretory activities. A small, triangular furrow with a round hole at its apex in soft sand or soil is a telltale sign of an echidna snout in search of food. Half-devastated termite mounds broken open by powerful claws are other indications of its feast, as are unmistakable blunt-ended scats. The feces have a lubricative membrane covering ingested soil and the chitinous remains of ants and termites, which account for the bulk of the short-beaked echidna's diet. Despite all these clues, the animal itself often remains unseen.

Even colonists who had lived in Semon's study area for many years admitted that they had never seen free-ranging echidnas. Semon himself chose to hire aboriginals to search for the elusive animals, stating that the "successful systematical capture of this animal is only possible with the intuitive tracking sense and hawk eyes of the native Australians." He attributed the aboriginals' success to the fact that they considered roast echidna a delicacy—a taste Semon did not share.

On the advice of the aboriginals, Semon spent the winter months studying monotremes, for that was the time of year when the animals were known to have young. During two years of fieldwork, aboriginals brought him more than 400 echidnas. Although Semon offered a higher price for the capture of females, only 127 were brought to him (a sex ratio of about one to three). We have found a similar ratio of females to males when collecting during the breeding season. We believe this proportion may represent a seasonal bias, a hypothesis we are investigating.

Semon collected and described the developmental stages of the egg and embryo in utero, as well as those of the pouch young. His investigations on the size of ovaries and testes led him to conclude that the echidna breeds once a year, between July and September. With the aid of the aboriginals, he also documented parental care.

Semon's scientific findings were published between 1894 and 1913 in a series of splendidly illustrated monographs entitled *Zoologische Forschungsreisen in Australien* [*see left illustration on page 101*]. Although monumental, his results only started to answer the questions Owen had originally posed about the echidna in 1864. Information was still lacking on its manner and season of copulation, the length of gestation, the nature of the temporary structures that nourish the fetus and provide oxygen to it, the size, condition and powers of the young immediately after birth and while suckling and, finally, the age at which the animal attains full size or becomes sexually mature.

Nearly 125 years later questions concerning the reproductive biology of monotremes remained unanswered. Then, in 1987, one of us (Seymour) initiated a study of the respiratory and metabolic development of the echidna egg during incubation. Again the first problem was "catching your echidna." We found that echidnas lead secretive, reclusive lives and that it required hundreds of hours in the field to locate a suitable population to study. Once we had found enough specimens to follow, however, radiotelemetry allowed us to relocate them on a frequent basis.

The more we worked in the field, the more we realized how little had been recorded about the echidna's natural history. Information on reproductive behavior in the wild was completely lacking. Ten thousand hours of fieldwork and the untiring assistance of Earth Watch and community volunteers began supplying some answers. Indeed, through daily tracking and diligent observations, we have discovered more than just how the secretive echidna copulates.

Early investigators were interested in how the echidna reproduced, but by necessity they studied preserved specimens, developing little knowledge of the animal's natural habits. We wanted to learn about the echidna's life cycle, beginning with the reproductive period. How do these solitary animals find each other during the breeding season? What social interactions take place? How do they mate without injuring each other?

During the breeding period, males actively seek out females over unknown distances and form "trains." We have found trains to consist of two to seven animals following one another in a row. In every train we examined, the lead echidna was a female. The smallest and often youngest animal was usually at the end.

Biologists still do not know exactly how the males find the females, but while we lay on the ground one meter away from a group of courting echidnas, we noted a strong musky odor given off by the female. (Semon recorded that both males and females gave off a pungent odor during the breeding season, but we have not yet been able to identify different sexual scents.)

On Kangaroo Island—our primary study site—trains of echidnas have been reported from mid-May to early September. We believe that the formation of trains marks the beginning of the courtship period. Fortuitous sightings of trains have been made along roadsides, on sheep paddocks or in open woodland. We have also discovered trains while searching densely vegetated sandhills or flat scrubland, all areas that the echidna inhabits.

On finding a train, we color code each echidna for future identification by slipping colored insulation tubing over a quill. A small radio transmitter is placed on the back of an animal before it is released at the site of capture. Individuals can then be tracked without disturbing their normal activities.

During courtship, groups of echidnas can be found foraging, walking or simply resting together for up to four weeks before mating behavior is observed. One or more males have been seen to prod the tail end of the female with their snouts, sniffing along her back or side from tail to head. Persistent males will go through this ritual for over an hour. If the female is not receptive, she curls up in a tight ball, exposing only her spiny back. This posture usually dampens the male's ardor, and he goes away—at least for a short time.

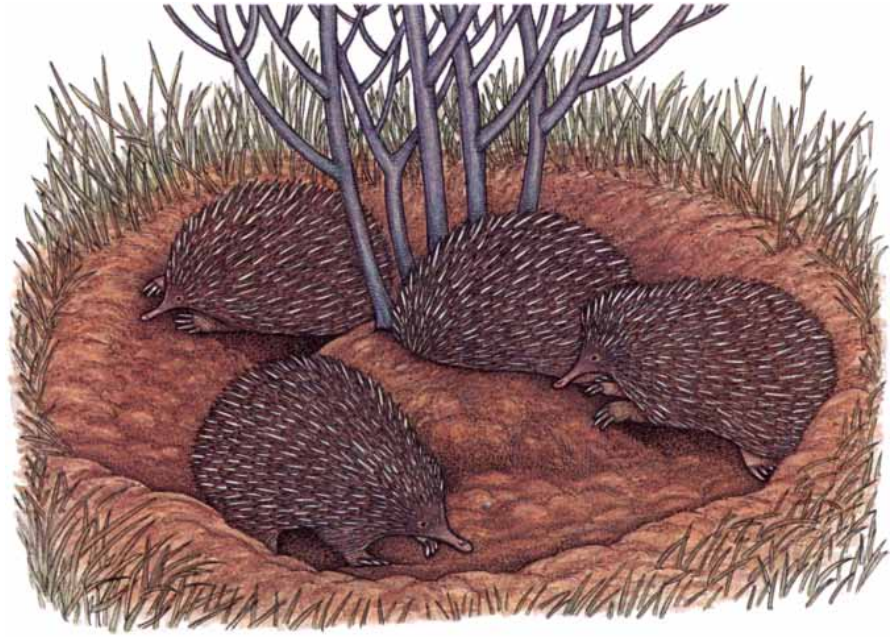
One drizzly, windy morning one of us (Rismiller) set out to track a female who had been observed with a train for 14 days. Although the literature states that echidnas stay inside on rainy days, the female and three males were on the slope of a hill thick with vegetation. The female's head was uphill, her front feet anchoring her to the base of a low tree. She was relaxed, quills lying down, and her body was spread flat, stomach against the ground. One male was lying directly next to her while the others nudged her with their snouts. It appeared she was ready to breed.

Then the three males, all with color tags, moved in single file around the base of the tree and the female. From time to time they halted, and a male would dig away the dirt on either side of the female as well as around her tail. Sometimes the males reversed direction while they dug around and prodded the female with their snouts. She remained placid as the trench around her and the tree grew deeper. We later termed the doughnut-shaped hole a mating rut.

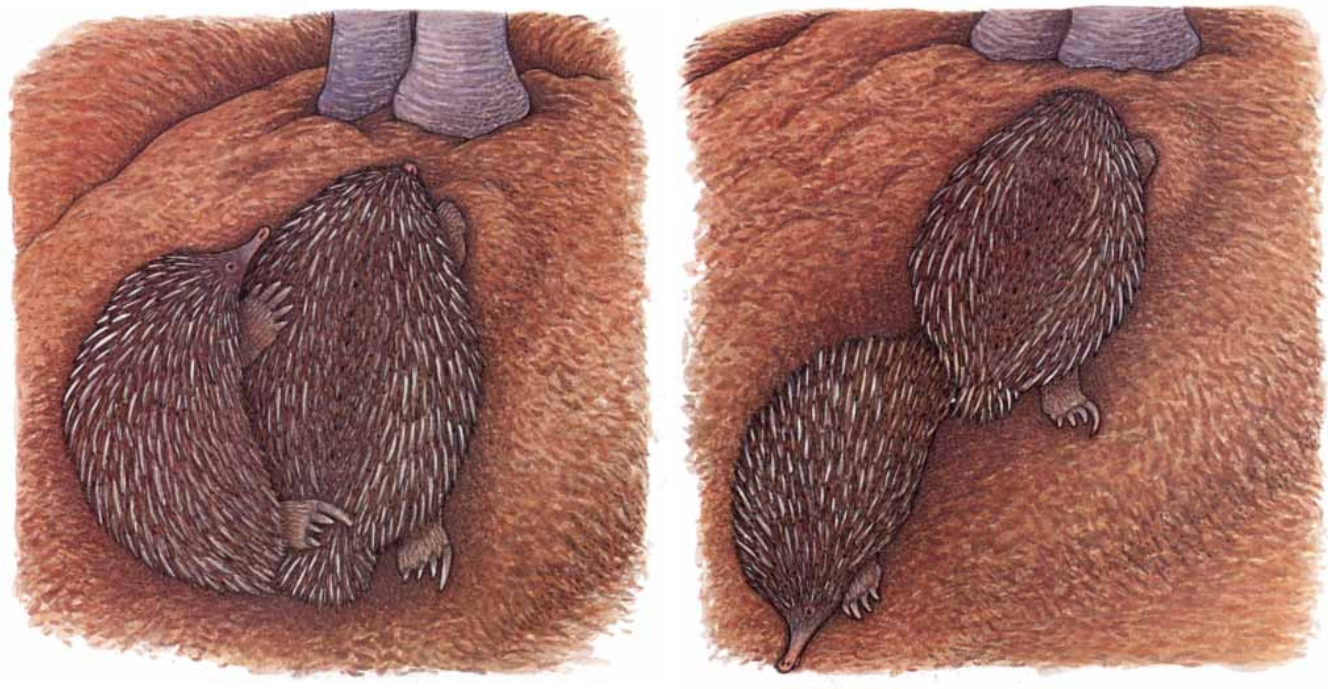
At one point the largest male turned toward one follower. They met head to head and tried to shove each other backward, out of the mating rut. The third male retreated without joining the competition and lay down a meter or so away from the others. Digging and shoving contests were repeated until only one male remained. The female, still quiescent and flat on her belly, never loosened the hold that her forefeet had at the base of the tree.

Without competitors, the male concentrated on digging directly around the female's posterior end, intermittently prodding under her tail with his snout. After once successfully raising her tail end with his forelimb, he then ran his front foot down her back. Her quills undulated with the stroke. Rear lifting and spine stroking continued while the male slowly worked himself on his side, nestling in the mating rut.

In this position the male could easily place his tail under the female's. Mating occurred cloaca on cloaca. I could see a joint pumping action of the tails,



MATING RUT is dug around a female by a train of as many as seven male suitors while she anchors herself against a tree. The doughnut-shaped rings, which range in depth from 18 to 25 centimeters, have puzzled bush walkers for many years.



COPULATION takes place tail to tail, usually when the echidnas are facing in the same direction. Sometimes, however, the animals face in opposite directions. The male lies on his side, placing his tail completely under the female's tail.

as well as a tensing and relaxing of quills in both echidnas. They remained together for about an hour. Then, penis still extended, the male left the mating rut (which measured 18 centimeters in depth). Shortly thereafter the female wandered off into the bush. Five hours had passed since the mating began; it was still raining.

We have also seen matings with only one male present. In these cases, open-ended trenches can replace circular mating ruts. Digging is focused on one side of the female and around her tail end until the male can lift her posterior and place his tail under hers. Copulation takes place in either of two positions: head to head or heads facing in opposite directions [*see illustration above*]. In either case, the tails are hooked together with the male turned on his side—nearly to the point of rolling over when no depression has been dug—and the female flat on her belly.

Early reports hold that echidnas mate solely in their burrows. We have watched a number of matings take place under the cover of low vegetation, in the open and above ground. We have also seen trains of five animals together in one burrow, where much digging had occurred. Before these recent observations, copulation between wild echidnas had not been recorded.

Although the early development of the fetus in utero has been documented, the hatching and the growth of the young are relatively undescribed. The first observations of gestation were made by naturalist Robert Broom in 1895, when a male and female echidna who had been captured "in copulation" were brought to him. The male refused to eat or drink and died 14 days later. On the 28th day after capture, the female laid an egg. Broom suspected that the male would have been physically incapable of impregnating the female after his first week in captivity "because of his poor condition," making the minimum period of gestation 21 days and the maximum 28 days.

In 1969 Mervyn Griffiths, the world's leading authority on monotremes [see "The Platypus," by Mervyn Griffiths; SCIENTIFIC AMERICAN, May 1988], and his co-workers found a female echidna accompanied by two males. Seventeen days later she laid an egg. Another female was found with males and was separated from them. After 34 days no pouch had formed, but an autopsy later revealed an egg in her uterus. Griffiths believes a gestation period of 34 days is far too long and speculates that the echidna, like some marsupials and reptiles, may be able to store sperm.

Although we did not watch the mating of each female that we tracked, we found the males in the train left the female between 21 and 28 days before she laid her egg. This timing may mean that the sexual attraction which brings and possibly keeps trains together disappears once the female has mated.

No one has ever seen how an echidna gets the egg from the cloaca—where it is expelled—into the pouch. Semon wrote that he could "report nothing on how the mother manages to place the laid egg in the pouch with her plump extremities or trunklike snout. The size of the egg compared with the narrowness of the mouth excludes it being picked up between the lips. Perhaps the echidna shoves the egg over the ground and into the pouch with her snout."

Griffiths noted that the cloaca of an echidna who had recently laid an egg protruded nearly as far as the posterior end of her pouch. This observation suggests that an echidna could lay an egg if she assumed a sitting position. We have often watched echidnas sitting upright on their tails without any back support, grooming their belly fur with their snouts. In this position the animal's cloaca can easily be extended to reach into the lateral folds of the pouch.

Echidna lore holds that some time after breeding the female retreats to a type of maternity burrow where she lays her single egg. Until recently, it was believed that she remained in the burrow, fasting during the incubation period and emerging only after the egg had hatched. The longitudinal stomach muscles forming the pouch did not seem strong enough to early observers to retain an egg safely while the mother was active outside the burrow.

During our fieldwork, however, we recaptured foraging females who were

carrying an egg. A deep pocket lies at the cloacal end of the elliptically formed pouch. We have always located the egg there, nestled protectively among the soft hairs.

Soft and leathery in texture, the echidna egg varies from round to slightly oval. It ranges from 13 by 13 to 16.5 by 13 millimeters in diameter—the size of a rather small grape. We have measured the mass of a dozen eggs and found they weigh between 1.323 and 1.893 grams. We could not definitely correlate egg mass with the size of the mother, but the heaviest—not the largest—egg was produced by the largest female. She weighed five kilograms, which is exceptional for a Kangaroo Island echidna—they usually average 3.8 kilograms, whereas those on the mainland are generally larger and average five kilograms.

An echidna egg is incubated in the mother's pouch for 10 to 10.5 days before it hatches. Griffiths determined this by examining the pouch of captive female echidnas twice a day. Among his many other contributions, Griffiths has verified and expanded on observations of egg development in the uterus and early embryology of monotremes made by zoologists J. P. Hill, J. B. Gatenby and T. T. Flynn in the 1920s and 1930s.

Very few people have actually witnessed the astonishing events of an echidna hatching. About a day before hatching, the egg forms a dimple. With some luck and diligent observation, we have seen the egg—probably the embryo within the egg—move.

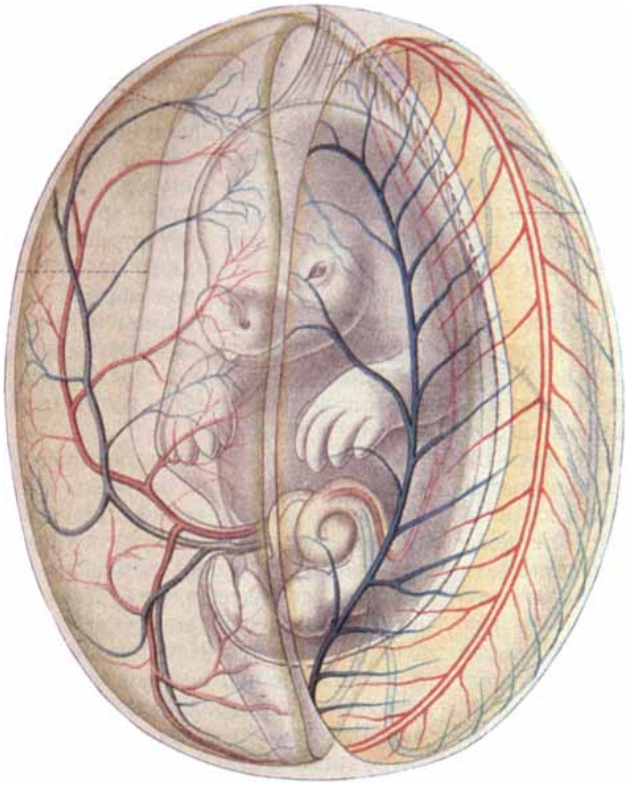
At hatching, the tiny echidna slits the tough, trilaminar shell with a special egg tooth. The young, still covered by a membrane, begins to wiggle and pull its way out of the shell. A mere 13 to 15 millimeters from crown to tail, the hatchling possesses amazing vitality and endurance. Its bursts of energetic movement are interspersed with periods of rest until it lies free in the pouch. Initially, the echidna's eyes are only rudimentary and covered with skin. Although the hind limbs appear as simple buds, the front legs and digits are already well formed, equipped with minute transparent claws for gripping the pouch hair. Because the egg is usually located at the posterior end of the pouch, the hatchling must travel six or more times its own body length for a first meal.

Unlike marsupials and other mammals, the echidna has no teats where the young can suckle. Instead the mammary glands, located anteriorly and on either side of the pouch, terminate in an area called the milk patch, or areola. This patch contains between 100 and 150 separate pores, each with a mammary hair follicle that is structurally different from that of other hairs. The hatchling, weighing only 0.27 to 0.39 grams at birth, finds its way to the milk patch—how it does so remains unclear. The hatchling's nasal openings are exceptionally large, and Griffiths has reported that its olfactory senses are well developed and functional.

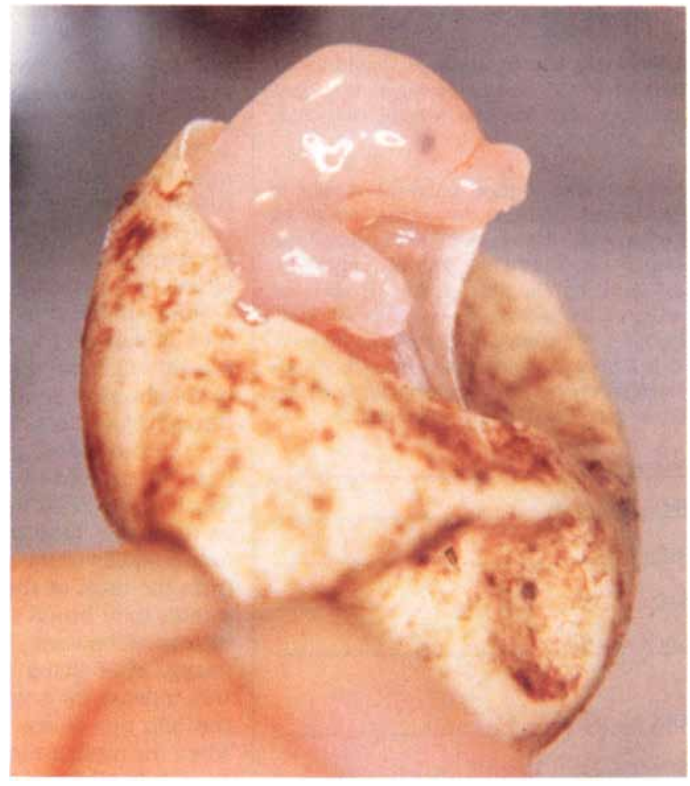
When it emerges from the egg, the body of the hatchling is semitransparent, and the remains of the yolk sac are visible. We have observed the newborn, four hours after hatching, clutching the hairs at the areola with milk filling its distended stomach. Contrary to the literature, young echidnas suck but do not lick the milk. Griffiths deduced this fact by studying the form and function of the tongue in pouch young echidnas.

Pouch young grow at a phenomenal rate. Hatchlings weighing less than half a gram can increase their weight to as much as 400 grams in about 60 days. Brian Green and his colleagues from the Commonwealth Scientific and Industrial Research Organization in Canberra measured the milk intake and weight increase of suckling echidnas and found that growth rate was related to the mother's size. Milk intake ranged from 7.6 to 36.4 milliliters a day, yielding a corresponding weight increase of 3.8 to 12.6 grams a day.

To keep up the massive milk production required to nourish the young, the



EMBRYO within the egg was published by Richard W. Semon in 1894. He depicts the yolk on one side and the vascular system extending around to the embryo's umbilical region.



TINY HATCHLING emerges from its leathery, oval egg. The enamel-covered egg tooth that is used to slit open the trilaminar, tough-skinned egg is prominent in this hatchling.

SCIENTIFIC AMERICAN

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POUCH YOUNG is still naked at 45 days when it begins to turn gray, marking the initial growth of hair and spines. Its ear slit can be seen on the left side of the head.

mother spends a great deal of time foraging. We have followed lactating females for hours on end. They travel at a steady pace through the bush, turning over stones and scratching under rotten, fallen timber for insect larvae or termites. One foraging female that we mapped traveled more than three kilometers in a single day.

Some of the female's feeding activities endanger the pouch young. On Kangaroo Island, meat ants are a highly sought after food source from July through November. Although adult ants are seldom eaten, echidnas savor the high fat content of the virgin queens, which move closer to the surface of the earth at this time of year. The dense fur and quills of the mother protect her from the bites of the ants, as she devastates their brood chambers. We have witnessed, however, a vulnerable pouch young, after being attacked by meat ants, release its grip from the mother and slip out of the protective pouch. When the mother moved on, the young was left behind and perished.

Scientists do not know if a female echidna who has lost either her egg or her pouch young early in the breeding season can reproduce again that same year. Although echidnas seem to have one reproductive period a year, there is no evidence proving that an individual female reproduces every year. In 1881 naturalist George Bennett speculated that a female may only produce one egg every other year, and this theory remains unrefuted. Some suggest that longevity may offset infrequent breeding in the echidna. A captive echidna in the Philadelphia Zoo lived for 49 years; the longest authenticated record from the wild is 16 years.

Aboriginals told Semon that a young echidna was carried in the pouch until it began to develop spines. The mother then left the still dependent young in a burrow, returning periodically to suckle it. Several years ago Griffiths determined that young are carried for an average of 53 days before they outgrow the pouch. He and his associates also observed free-ranging, lactating echidnas. They found that the intervals between suckling the young in the burrow varied between five and 10 days. Milk intake at one feeding was as great as 20 percent of the young's body weight. Between feedings the female traveled

great distances. Together with another group of researchers, Griffiths discovered that the milk composition of the female echidna changes as the young grows. They found that the lactation period lasts about 200 days.

The burrow where the young is placed can be anything from a warm, dry nursery tunneled under a termite mound to chambers under a pile of garden refuse close to buildings and a busy road. Even within the nursery, the young echidna is not safe from natural predators. On more than one occasion, we have seen a Kangaroo Island goanna—a large lizard—attempting to eat a young echidna. In each case, the animal was too large to be ingested, but the injuries led to death. In other areas, large snakes may also feed on burrow young that have not yet developed long spines. Currently the greatest predatory threat throughout Australia is posed by feral cats, foxes and dogs.

Despite our growing understanding of the echidna's reproduction and development, the natural life span and daily habits of the animal are still largely a mystery. Our ongoing studies seek to clarify several points. We would like to know whether, and to what degree, a relationship exists between the mother and her offspring once the young leaves the burrow or whether the innate inquisitive nature of the young suffices for survival. Because yearlings are not sexually mature, we hope to discover the age at which animals become capable of reproducing and whether both sexes mature at the same age.

The echidna is a unique native Australian animal. Although it is widely distributed and reportedly common, there are no numbers or facts as to what defines a healthy population. Because of the impact of human activities, both past and present, many native animals and their habitats need protection—and the echidna is among them. No significant action can be taken, however, until the animal's biology and ecology are adequately documented and understood. Currently not enough scientific evidence is available to provide a sound basis for evaluating the future conservation needs of this ancient species.

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Computers and Architecture

Advanced modeling and rendering algorithms allow designers and clients to walk through buildings long before construction

by Donald P. Greenberg

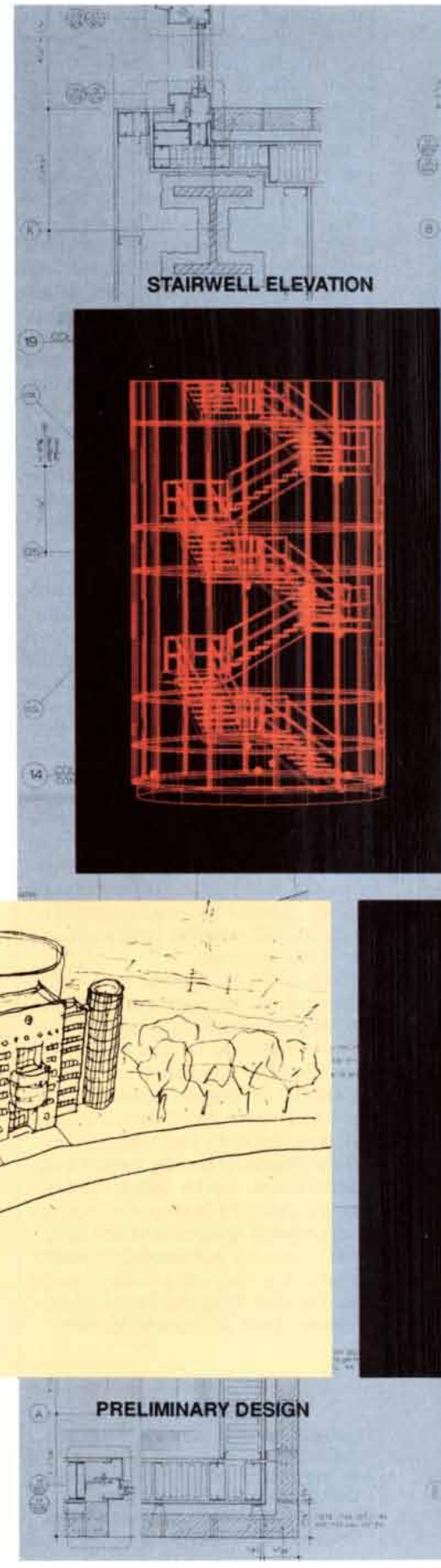
When it comes to designing a building and its interior spaces, architects still rely on sketches on the backs of napkins. They and their clients evaluate completed designs on the basis of hand drawings or painstakingly crafted miniature models. Many so-called computer-aided design systems employed by architects are in reality only computer aids to drafting. They automate the production of working drawings, but they do not provide the perceptual cues—color shading, shadows, texture and motion—that are necessary to evaluate an architectural space.

New software and advanced graphics-rendering techniques, however, are beginning to contribute to the creative side of architecture. These programs relieve the designer of labor-intensive drawing and provide more freedom to explore new ideas in three dimensions rather than just two. Architects can work through the entire preliminary design process—sketching and exploring aesthetic alternatives, refining their designs and generating realistic images for analysis.

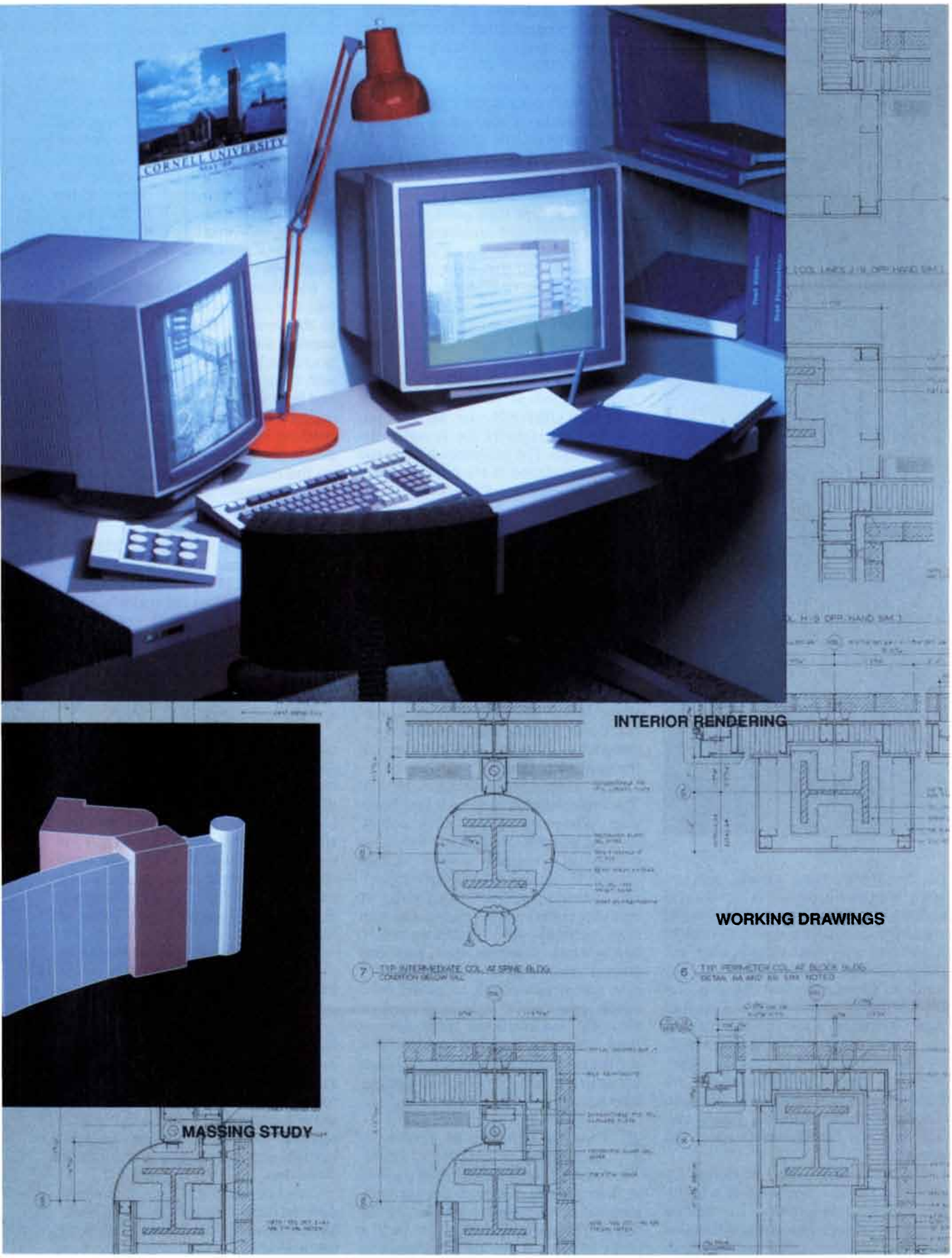
Such sophisticated graphics programs, already at work in research laboratories and in architectural design courses at Cornell University, produce images much more useful to architects and clients than the drawings and models now employed. The images capture subtle nuances of light and shadow, and—most crucial to understanding how the finished design will work—they can be displayed in rapid sequence to give the impression of moving through a building as it will look after it has been constructed.

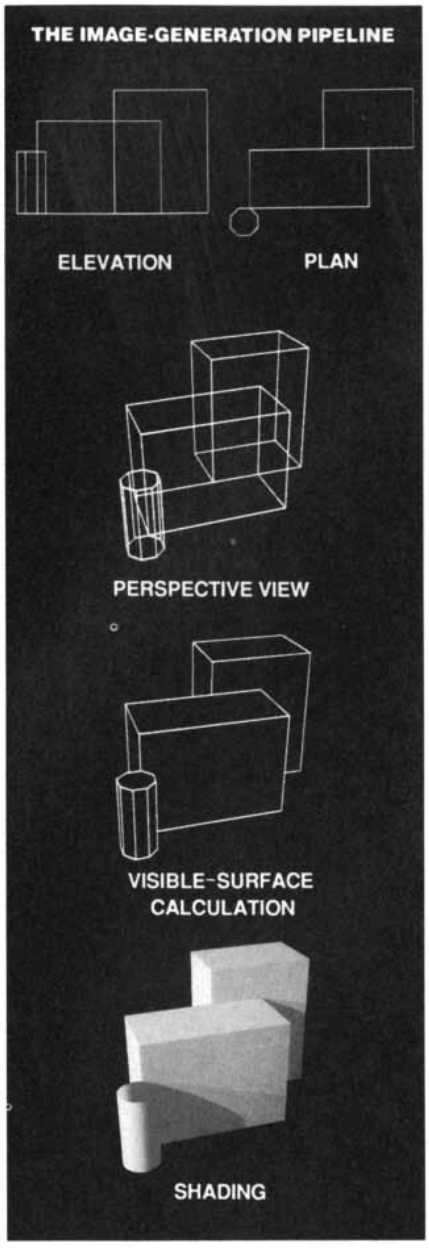
Architectural software must satisfy the unique characteristics and quirks

DONALD P. GREENBERG is director of the computer graphics program at Cornell University, where he also teaches architecture. He and his colleagues apply computer graphics to modeling problems ranging from the design of buildings and stage sets and lighting to simulation of basic physics. He received his Ph.D. in structural engineering from Cornell in 1968.



***ARCHITECTURAL DESIGN** process begins with simple sketches* (above) *and progresses through increasing levels of detail to the working drawings from which a structure (such as Cornell University's Theory Center) is built. New software and hardware can facilitate all but the earliest steps of the process.*





of the architectural design process. Most important, design is iterative: if architects encounter a roadblock while refining a design, they must go back to a previous stage and rethink their initial decisions. During each stage, the mode of communication changes subtly. The initial process starts with doodles on tracing paper or sketches on the backs of envelopes. Later stages add more and more detail and refinement as areas and dimensions are fixed. Pencil gives way to ink. Standard details such as windows, doors and wall sections are incorporated in the drawings.

The preliminary stage of design focuses on the size and scale of a building and its relationships to existing structures nearby, amassing studies to establish the basic shape and composition of the structure, and the satisfaction of programmatic requirements such as the number of square feet required in different parts of the building. The next phase, design development, encompasses the refinement of plans, elevations and cross sections, traffic patterns, the clustering of private and public spaces, and the layout of individual rooms. The working-drawing phase—currently the most expensive and time-consuming—produces a set of detailed drawings that provide exact dimensions and material specifications so that the building can be constructed. They also ensure compliance with building codes and budget requirements, and they help to protect the architect against contractual misunderstandings.

Currently available commercial programs, aimed at producing working drawings efficiently, are far too unforgiving to support the iterative design process. The programs require too much information in too precise a form to be useful for doodling. Furthermore, drafting software is generally not designed to produce high-quality renderings suitable for communicating the feel of a building's spaces.

Historically that task has fallen to painstakingly constructed small-scale physical models. Such models are expensive and inflexible, and they can generally only provide a bird's-eye view of a building or interior. They certainly cannot give an architect or client a true sense of the perspective, colors, textures and shading that would be perceived by someone walking through the final structure.

Only computer graphics can do that. The extraordinary software and hardware advances of the past decade make it possible to generate full-color images of complex scenes rapidly enough to portray motion. Such modeling software can create renderings of complex environments containing specific materials with particular colors and textures—concrete, steel, glass and fabrics. Image-synthesis algorithms are now advanced enough to model even subtle nuances of light and shadow. Powerful workstations incorporating these algorithms permit architects to see the results of their design decisions immediately and to revise their designs interactively.

Creating a picture of a scene is a five-step process. First the architect must define the objects in it, their shapes, positions, orientations, material characteristics and surface finishes. The second step is to pick a point of view, a process analogous to positioning a camera and selecting and focusing the lens. The computer then transforms the object data to create a perspective image.

The third step is to determine which surfaces are visible to the observer. In the real world, physical laws take care of this problem, but computer-generated scenes require time-consuming calculations to solve the so-called hidden-surface problem. All objects in the scene must be checked to determine whether they overlap; if they do, only the object closest to the observer is displayed.

The fourth step is to simulate lighting. The light incident on any surface in the scene is a combination of that coming directly from sources (whose positions have been determined along with those of other objects in the scene) and light reflected from other surfaces (indirect lighting). The intensity of light reaching the observer, furthermore, depends both on the incident light and on the reflective qualities of each surface. To simplify the rendering process, many systems calculate only the direct illumination of surfaces.

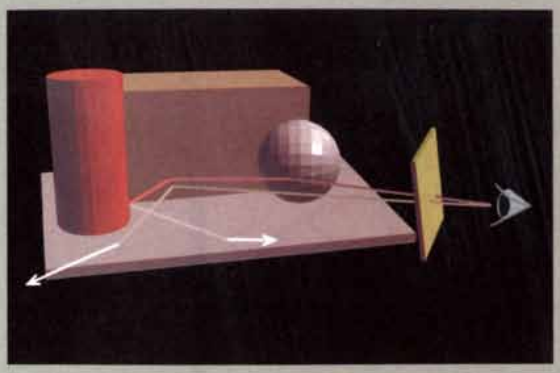
The last step is display. The rendering software must determine the amount of light that would reach the observer's eye from the real scene and generate an image that creates the same visual effect. The colors and intensities the software chooses may differ depending on whether the image is to be displayed on a screen, printed or shown as a color slide.

In modern high-performance graphics workstations, special-purpose hardware directly implements perspective transformations, visible-surface determination and display routines. This hardware can also execute the algorithms required to model simple direct illumination. Workstations carry out the graphics computations fast enough that architects can model their designs and evaluate them easily at early stages.

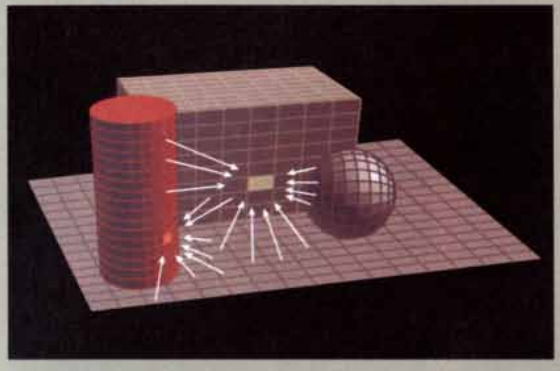
The quality of images produced by most workstations is limited, however. Pictures can easily be recognized as computer generated because they do not include the effects of interreflections among objects. As a result, they are useful primarily for initial modeling. Design evaluation requires much more realistic images, generated by more sophisticated software. Furthermore, these images must be displayed in rapid sequence to create the illusion of motion.

Computer graphics researchers have devoted considerable effort to the problem of lighting. The effects of lighting and reflection in real scenes are very

TWO METHODS FOR SIMULATING LIGHT AND SHADING



RAY-TRACING method for generating computer images sends imaginary rays of light from the viewer's eye into the scene being rendered. The color and light intensity at each point in the image depend on the reflectivity of the surfaces encountered by the ray in its passage through the scene.



RADIOSITY ALGORITHM calculates the light intensity of each surface in a scene as a function of the intensity of all other surfaces. Once the resulting set of simultaneous equations has been solved, the scene can be rendered rapidly from any angle.

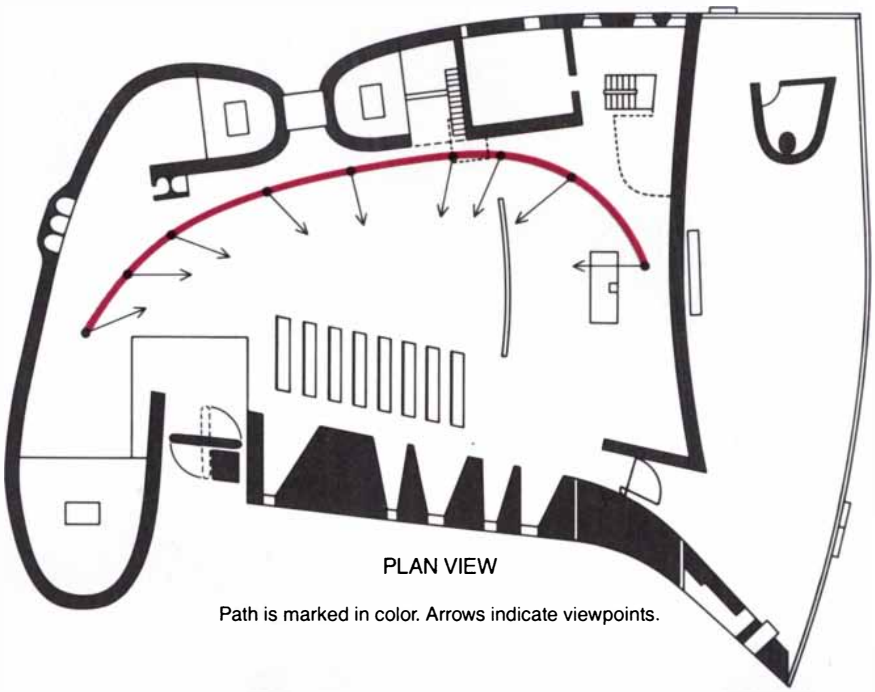
complicated and subtle. Indirect lighting is particularly difficult to model. It is possible to write equations that accurately simulate this global illumination, but they consume unreasonable amounts of processing time.

Two short-cut methods have become popular in the computer graphics community: ray tracing and radiosity. These techniques represent almost diametrically opposite approaches to generating an image. Ray tracing concerns itself only with light that enters the observer's eye and is particularly appropriate for environments that contain highly reflective surfaces. Radiosity, in contrast, determines the distribution of light energy throughout a scene and is best suited to environments containing mostly matte surfaces.

Although ray tracing produces extraordinarily realistic images and can certainly be used for architectural presentations, its value for design evaluation is limited. The approach is view dependent, and so the entire computation must be repeated for each new viewpoint. Ray-tracing algorithms work too slowly to generate dynamic sequences that show an architect or client what it would look like to walk through a space.

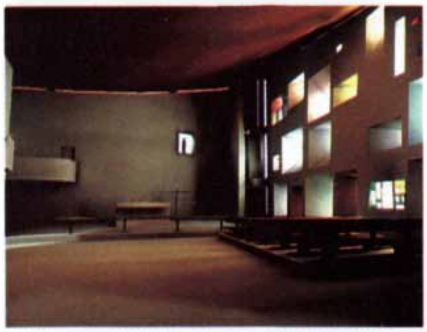
The radiosity approach, developed at Cornell in 1984, is view independent: it makes its calculations only once for a given scene. Once the global illumination has been determined, it is easy to create a series of pictures from different viewpoints. Indeed, the algorithm

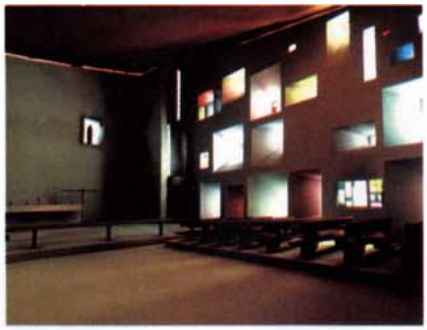
A WALK THROUGH
LE CORBUSIER'S CHAPEL AT RONCHAMPS

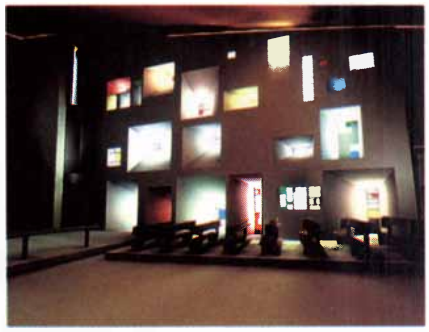


PLAN VIEW

Path is marked in color. Arrows indicate viewpoints.







COMPUTER MODEL gives the impression of moving through a space. Image-rendering software running on high-performance graphics workstations can generate views of a structure from any position at rates of several frames per second or more. Such walk-throughs are of use both in evaluations of structures yet to be built and in studies of existing buildings. The balcony at Ronchamps (left)*, for example, is not usually accessible to the public.*

can generate images fast enough to give the illusion of motion.

Ray tracing reverses the usual laws of light propagation. In the real world, light rays spread out from each light source in a scene and reflect from surfaces in the scene; eventually a small proportion of all the light rays pass into the eye of the observer. Instead ray-tracing algorithms follow the paths of the light rays back from the eye through the scene to the surfaces and light sources that engendered them.

The most popular method for modeling global illumination using ray tracing was introduced by Turner Whitted of Bell Laboratories in 1979. It traces the path of a single ray from the eye through each point in the image plane (each pixel on a workstation screen, for example) into the environment. Whenever the ray strikes a surface, it spawns reflected or refracted rays, which in turn are traced to establish the surfaces they intersect. The final intensity of each pixel is determined by adding up the light contributed by each spawned ray.

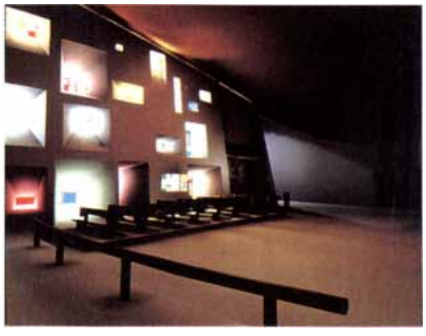
***COLOR AND TEXTURE** of computer renderings (such as this hypothetical museum of constructivist modern art) can be changed simply and quickly. Architects and their clients can evaluate different choices of construction materials and color schemes at minimal expense.*

Radiosity relies on the conservation of energy to determine accurately the light intensity for each surface in a scene composed of ideal diffuse emitters and reflectors. An equation can be written defining the radiosity of each surface in a scene—the intensity of light leaving the surface—as a function of the radiosity of all the other surfaces. The radiosity of an object depends on two factors: emission (if the object is a light source) and reflection of incident light. The incident light, in turn, depends on emission from all the light sources in the environment and reflections from all the other surfaces.

The radiosity values for all the surfaces are then expressed as a matrix of simultaneous equations that can be solved to yield values for the illumination of any given part of the scene. Currently the computation is tractable only for diffuse environments; complex patterns of emission or reflection make the equations too difficult to solve quickly.

Radiosity is not only fast (after the initial calculations have been done), it is also very accurate. It can reproduce such phenomena as "color bleeding," in which reflections from a red surface, for example, might make an adjacent white surface look pink, variations of shading within shadows, and the fuzzy shadow edges produced by extended light sources such as skylights or fluorescent light fixtures.

Computer-aided design systems can now produce the kinds of images architects need. The most important issue yet to be resolved is software that makes it easy for architects to create their models. Researchers are only now coming to grips with the kinds of operations required to design a building—creating shapes, specifying surface qualities, joining objects together into seamless composites. Although the initial rough sketches for a design may always be done on paper, the coming decade will see programs that are simple to learn and to use yet powerful enough to handle the design of entire buildings down to the smallest detail and capable of generating moving, photorealistic images.



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The Acoustics of the Harpsichord

A complex interplay of string, wood, air and the human ear produces the swirling sound of the harpsichord

by Edward L. Kottick, Kenneth D. Marshall and Thomas J. Hendrickson

Late 18th-century music lovers could debate the merits of three common stringed keyboard instruments. The piano, its strings capable of being jarred into motion by forceful blows of its hammers, became the most enduringly popular instrument. It could make powerful crescendos and gentle diminuendos. The soft-voiced clavichord, sounded by striking the strings with brass blades, could make crescendos and diminuendos but only at the low end of the volume scale. Nevertheless, it was small and relatively inexpensive to build. The harpsichord was the only member of this group whose strings were plucked. Unable to provide such variation in loud and soft sounds, it gradually lost favor among European society and, by 1809, when the last one was built, seemed destined to become a fusty relic.

Then, 80 years later, musicians realized that no other instrument could substitute for the distinctive sound of the harpsichord. The instrument had a musical superiority in the performance of Baroque and earlier music that the piano could not match. Harpsichord manufacture began anew in 1889, and, thanks to this revival, the keyboard music of Bach, Purcell, Rameau, Couperin, Scarlatti and Handel is once again heard on the instrument for which it was composed. Curiously, despite five centuries of existence, how the harpsichord produces its resonating sound remained until recently poorly understood.

Because much is known about the piano, violin and guitar—instruments to which the harpsichord bears an apparent resemblance—one might suspect that, by analogy, acousticians can make some basic assumptions about the harpsichord. Like the piano, it has a case and a soundboard crossed by strings. Like the violin and guitar, it has a soundboard, sides and a bottom enclosing a volume of air. But the similarities are illusory. The modern piano has a thick soundboard and massive sides; it has no bottom and therefore does not enclose a volume of air. The violin and guitar are at least superficially symmetric. The harpsichord is decidedly not, and its bridge is measured in feet rather than inches. If not unique, then the harpsichord is at least unusual in its construction and acoustics.

Harpsichord makers developed two general methods of construction. Adherents of the Southern style, primarily in Italy, built instruments with short scales: the length of string that sounds the C one octave above middle C is from 10 to 11 inches. With something of an explosive quality to the pluck, the tone is clear, penetrating and resonant. Flemish builders, on the other hand, conceived a bulkier, less fragile instrument with longer scales, typically about 14 inches. Tonally, the Northern-style harpsichords achieved a dark, suave sound quite different from their Italian counterparts.

Hoping to gain some understanding of the harpsichord's acoustical mysteries, one of us (Kottick) and the late physicist William R. Savage established an acoustics laboratory at the University of Iowa in 1976. In the ensuing years and with help from other researchers, we studied the physics behind the instrument, deriving considerable data from a Flemish-style harpsichord we constructed. We also studied antiques from the Metropolitan Museum of Art in New York, the Yale University Collection, the Smithsonian Institution and the Boston Museum of Fine Arts and looked at newly built instruments from Zuckermann Harpsichords in Stonington, Conn. All in all, we examined 39 instruments.

Harpsichords are fundamentally designed to convert mechanical energy into pressure waves that are transmitted to the ear through the air. A player imparts the mechanical energy to the keyboard, which consists of wood levers that rock up and down on pins projecting from a balance rail.

On the distal end of each key lever sits one or more jacks. The jacks ride up and down in slotted wooden battens known as guides. Each jack consists of the jack body itself, a tongue that pivots in the body, a spring to return the tongue to its resting position, a plectrum (a pick) and a cloth damper.

Depressing a key raises a jack that,

EDWARD L. KOTTICK, KENNETH D. MARSHALL and THOMAS J. HENDRICKSON have been studying musical acoustics for many years. Kottick is professor of musicology at the University of Iowa and a harpsichord builder. He has researched the physics of the harpsichord for 15 years. Marshall, manager of tire research at the Uniroyal Goodrich Tire Company in Brecksville, Ohio, became interested in the physics of music in 1982 and conducts research on vibration and acoustics. Hendrickson is emeritus professor of physics at Gettysburg College in Pennsylvania, where he taught musical acoustics. His particular interest is in the behavior of the air in the harpsichord cavity. The authors dedicate this article to the late William R. Savage, a solid state physicist at the University of Iowa, who helped to direct the early research.

ITALIAN-STYLE HARPSICHORD, restored in the 19th century from 17th-century parts, depicts a bucolic scene on the lid and cupids and wreaths on the exterior. Flemish-style instruments tended to be even more highly decorated and ornate.

in turn, presses its plectrum against the appropriate string. The lifting action of the plectrum puts a kink into the string. Then, with just a little more pressure, the string slides off the plectrum. Next the kink traverses the length of the string, hitting the bridge pin. Here the kink transfers some of its energy to the bridge, which then meters the energy to the thin, flexible soundboard. The kink is immediately reflected back toward the nut. Because the nut is set on a massive and stable wrest plank, little of the kink's potency dissipates there.

Thus, the kink is reflected back and forth from nut to bridge. On each traverse, the kink transfers some energy to the bridge. The string finally comes to rest after transmitting its energy to the soundboard and, to a lesser extent, to the air surrounding the string. (Multiple jacks on a key allow for greater tonal variety; each key of our laboratory harpsichord, for instance, has two jacks—and consequently two strings connected to different bridges.)

The speed with which the kink travels depends on the mass per unit length and the tension of the string. The combination of the speed of the kink with the distance it travels—that is, the length of the string—defines the rate of vibration. Thus, a kink that makes 440 round-trips a second produces the A above middle C. This is the "A = 440 hertz" known to all musicians and represents the fundamental tone of that string. Other strings are tuned to different notes.

But the harpsichord string actually vibrates in a much more complex manner than we have described thus far. While oscillating at 440 hertz, the string is also vibrating in halves, near 880 hertz. Simultaneously, the string vibrates in thirds, near 1,320 hertz; in fourths, near 1,760 hertz; and so on. These various modes of vibration are known as partials, or overtones.

Strings would like to oscillate as closely as possible to harmonic partials, or whole-number multiples of the fundamental. In practice, the partials do not occur at precisely those simple ratios, because strings have thickness as well as length, which lends them "inharmonicity," or an inability to vibrate harmonically. Inharmonicity is part of the harpsichord's tonal quality. Without it, one would probably characterize

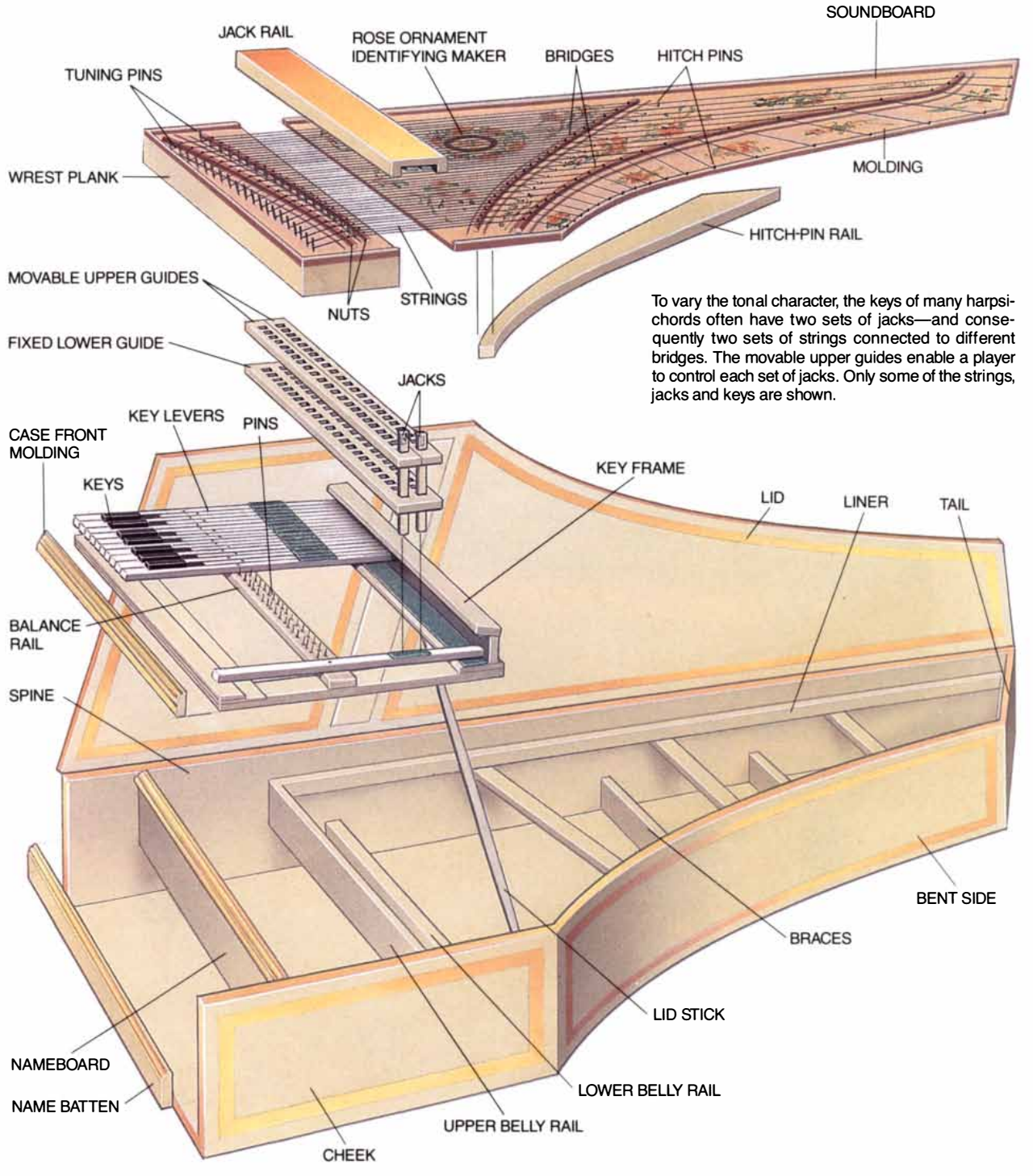
the sound of the instrument as somewhat bland.

Because the string has modes of vibration other than the fundamental, the bridge must deal with the energy of all the partials as well as the fundamental. The bridge, however, tends to be discriminating. It governs the strength of the excitations produced by some partials and may deny others any access to the soundboard. It also meters the rate at which energy is transferred from the string to the board.

The efficiency with which the bridge performs these chores depends on what is called the impedance match between the strings and the soundboard. A perfect impedance match, with no obstruction or reflection from the bridge, would allow all the energy of the vibrating string to be transferred to the board at once. The result would be a loud and not too musical "bang." A poor impedance match would have just the opposite effect. It would take a long time for the energy of the vibrating string to dissipate, but little sound would be heard.

The soundboard, a thin plate made of eighth-inch-thick spruce, is approx-

ANATOMY OF A HARPSICHORD



To vary the tonal character, the keys of many harpsichords often have two sets of jacks—and consequently two sets of strings connected to different bridges. The movable upper guides enable a player to control each set of jacks. Only some of the strings, jacks and keys are shown.

imately triangular in shape; its grain runs in the long direction. It is one of the most mysterious elements of the harpsichord. The soundboard's efficiency depends on its shape, thickness, mass distribution and grain pattern as well as on the characteristics of the bridge and the various ribs and members glued to the undersurface.

Attached firmly to the case, the soundboard is glued to liners that encircle the spine, tail, bent side and cheek. The front of the board attaches to the top of the upper belly rail, a structural member that extends from spine to cheek. Like a loudspeaker, the soundboard can vibrate at all significant frequencies. But it also has eigenmodes, or normal modes of vibration, that occur at favored frequencies. At these frequencies, the soundboard resonates with much greater amplitude than at other frequencies and thus imposes its own characteristics on the energy imparted it by the vibrating string.

One of our first attempts to understand soundboard behavior was to study frequency-response curves and eigenmode patterns of a number of harpsichords. Such analyses would identify the frequencies where resonance occurred. The timbre of the harpsichord, like that of other instruments, depends in large part on how the fundamentals and partials of the strings excite resonances.

To generate the response curves, we used a signal generator to produce a sinusoidal frequency—a pure tone—at the bridge pin of each string. A sound-pressure level meter measured the response of the harpsichord to the sinusoidal stimulation. In this manner, we obtained response curves for the fundamentals of all the notes.

Although the curves served only as a rough measure of the characteristics of each instrument, we could draw some tentative conclusions about the properties of harpsichords. First, soundboards have many resonances, all fairly broad. Second, extremely prominent resonance peaks identify the type of harpsichord. Northern harpsichords have three to seven of these prominent peaks, which all occur below 400 hertz. Italian harpsichords, on the other hand, have no more than three prominent resonance peaks, usually between 100 and 200 hertz.

To study the resonances visually, we spread decorative glitter evenly over the surface of the soundboard. This method of analysis, named for the German physicist Ernst F. F. Chladni, provides a graphic way of demonstrating the vibrational patterns of plates and membranes and identifying their eigenmodes [see "The Acoustics of Violin Plates," by Carleen Maley Hutchins; SCIENTIFIC AMERICAN, October 1981]. When the soundboard vibrates at one of its resonant frequencies, the glitter bounces out of regions that are moving and collects along nodal lines, or areas where the soundboard is not vibrating. The glitter surrounds the areas of maximum motion, forming elliptically shaped "hot spots."

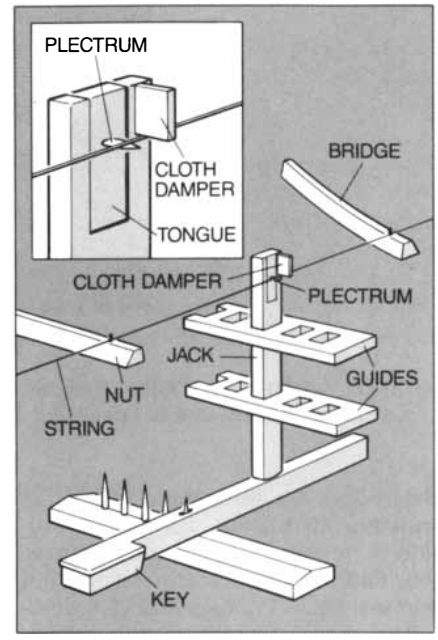
The Chladni patterns were quite informative. Contrary to what common sense might suggest, the sections of the soundboard that vibrated with the greatest amplitude were usually located away—occasionally at some distance—from the area directly beneath the bridge pin being driven. This observation shows the importance of a proper impedance match between the strings and the soundboard. If the area where the string crosses the bridge moves a great deal, the energy of the vibrating string would be transferred too readily, resulting in musically undesirable sound.

The generally elliptical shape of the hot spots occurs because of the grain structure of the spruce. Sound in spruce travels about four times faster along the grain than across it. The ellipse is not perfect, however, because of braces and bridges. In Northern harpsichords the orientation of the pattern is the same as those of the bridges, hitch-pin rail and cutoff bar (a structural support attached to the underside of the soundboard). Italian boards are frequently braced at nearly right angles to the spine or bridges. This positioning tends to even out the velocity of sound traveling in different directions; Chladni patterns of Italian harpsichords are thus more circular than those of the Northern type.

Finally, the patterns indicated that almost every location on the soundboard moves a fairly large amount at one or more frequencies. The entire board at one time or another participates in some modal behavior.

Like the response curves, the Chladni patterns revealed the general characteristics of the harpsichords. But they could not reveal the fine structure, and they tell little about what happens at places other than the soundboard.

We gained a fuller understanding of the physical behavior of our laboratory harpsichord through a mathematical tool known as modal analysis. This technique allows an investigator to describe the dynamic response of a structure through its modal properties: its resonant frequencies, damping characteristics and relative motions at different locations.

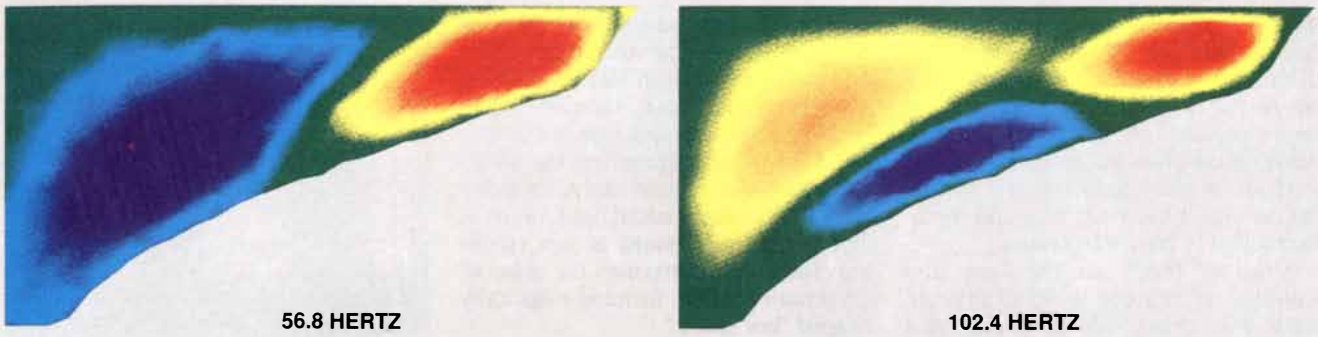


HARPSICHORD JACK rides in upper and lower guides. Its plectrum plucks a string (*inset*), and the vibration is transmitted to the soundboard via the bridge.

We attached two accelerometers—small electronic devices that convert physical motion into electric signals—to the underside of the soundboard. To excite the vibrational modes, we tapped the various parts of the harpsichord with a small hammer. In all, we tapped at 605 locations, more than 300 of which were on the board alone. A computer recorded the data signals and calculated the eigenmodes.

The computer-generated modal maps confirmed the information derived from the Chladni patterns, including the positions of the hot spots and the nodal lines. The modal analysis also uncovered a wealth of detail impossible to achieve through the use of Chladni patterns alone. These details revealed, somewhat to our surprise, that the case of the harpsichord was actively involved in the vibrational motion. In fact, at some low frequencies, the amplitude of motion of the case rivaled that of the soundboard. A computer-generated, three-dimensional video of the eigenmodes showed how the case pitched about the location of the stand; it often resembled a plate twisted about the long axis. Nor were the keyboard, the heavy wrest plank and the lid stationary; they also danced to tunes played by their own families of eigenmodes.

Only some of this vibrational activity contributes to the radiating sound of the harpsichord. Most of the motion



NORMAL MODES OF VIBRATION, or eigenmodes, of the soundboard are revealed in false color through modal analysis. The images show the varying degrees of motion—strongly upward (*red*), slightly upward (*yellow*), slightly depressed

determines the instrument's "feel." A truly fine instrument, one that in addition to its sound has a quality of "user friendliness" to it, seems to result from just this kind of nonmusical vibration.

The modal picture of the soundboard becomes increasingly complex at the higher resonance frequencies: the size of the hot spots decreases, and their number grows. The regions of the soundboard on either side of the bridges have fairly uniform thicknesses, in some ways resembling long, thin membranes. Here a series of hot spots develops and progresses, more or less uniformly, along the length.

Well hidden beneath this abundant and nearly incomprehensible activity lies an important piece of information. Between zero and 600 hertz we discovered 36 distinct modes. This amounts to one vibrational mode per 16.7 hertz, a fairly high density of activity. Such density increases the chance that a string partial will excite a mode.

The wood is not the only part of the harpsichord that moves. Because the instrument has a bottom, the whole forms a box enclosing a volume of air. When the soundboard moves, this air mass also vibrates. And like the board, the air has favored modes. In its simplest form the air cavity can be considered a wedge-shaped room bounded on its sides and bottom by fairly rigid boards and enclosed on top by a flexible soundboard. This room, however, has a slightly drafty picture window: the gap between the upper and lower belly rails, which lie just behind the keys, jack and keyboard rack, enables some air to leak through.

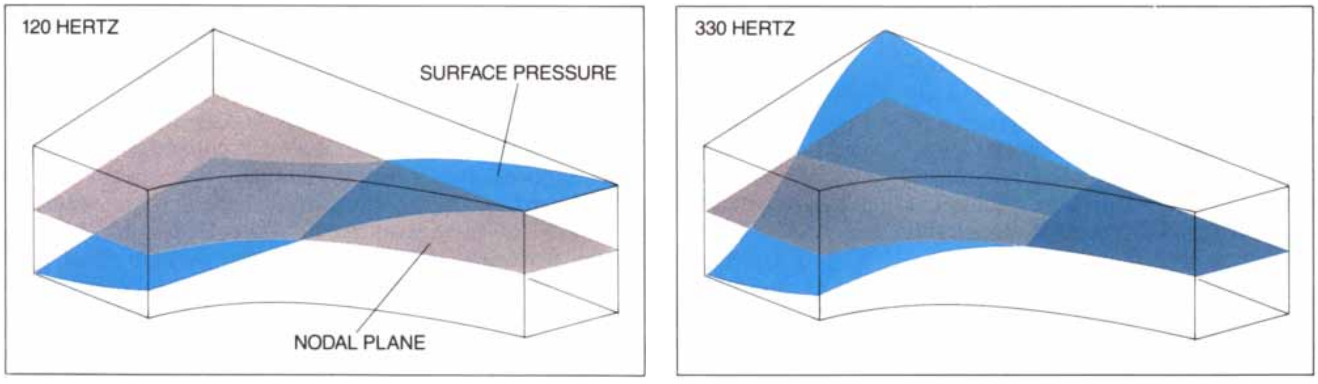
Researchers can predict the kinds of eigenmodes that occur in the wedge-shaped room by referring to the mathematical theory of waves. In this case, the wave equation predicts that three families of eigenmodes can share the harpsichord's air cavity. The first has standing waves in the vertical direction—from floor to ceiling, so to speak. These modes start at high frequencies, beginning at about 945 hertz, and recur at harmonic intervals.

We found the other two families of air-cavity modes by obtaining mathematical function solutions to the wave equation. These solutions indicated that one family sets up waves that spread out from the tail of the harpsichord. The waves reflect back when they reach the area of the belly rails, setting up standing waves in the cavity. The frequencies for this family start out fairly low. The eigenmodes appear at regular (but not harmonic) intervals above the starting frequency.

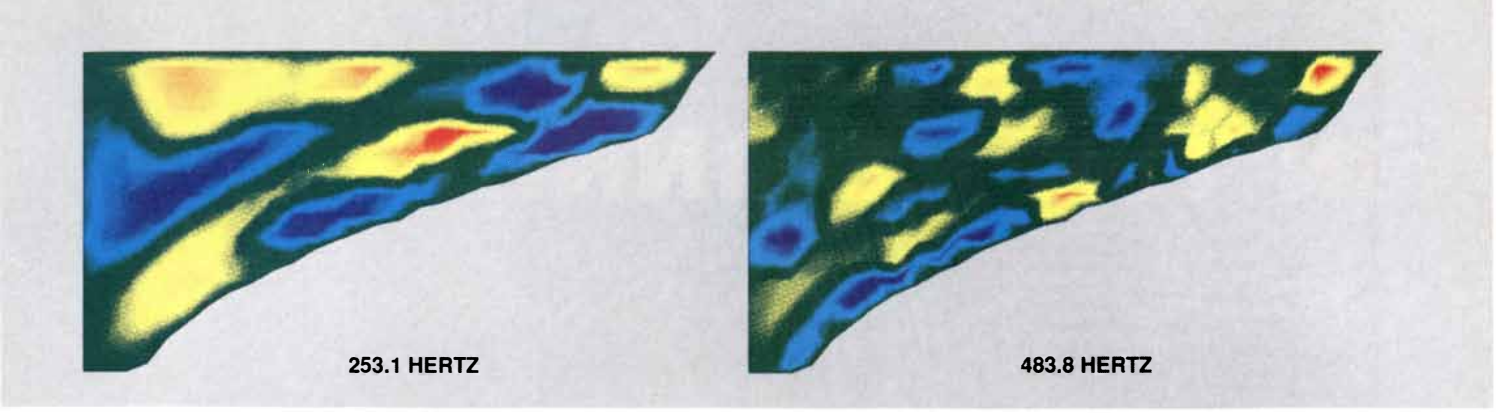
The third family has a nodal surface running down the center of the air cavity. Crests and troughs are again present, but they occur in pairs on either side of the nodal surface, with a crest always opposite a trough.

Although these solutions revealed what modes existed in the air cavity, the normal modes needed to be measured experimentally to determine their strength. We projected sound into the cavity with an acoustic driver (a kind of loudspeaker). Six small microphones in the cavity picked up the resulting acoustic resonances.

These data indicated that the eigenmodes with the greatest strength were those that were strongly reflected at the gap between the belly rails. A small amount of leaking occurred at low frequencies, particularly for the first eigenmode, but the prominent modes were similar to the type generated by a pipe closed at both ends. This information means that the air-cavity modes cannot



AIR-CAVITY MODES of the harpsichord, shown here for 120 and 330 hertz, result from the motion of the soundboard. Although the air does not directly contribute to the sound, it influences the board by acting as a load or as an internal spring.



(*blue*) and strongly depressed (*violet*). Areas where the board is not moving are called nodes (*green*). In all, 36 eigenmodes were discovered between zero and 600 hertz (the lowest G is about 50 hertz and the A above middle C is 440 hertz).

contribute directly to the sound radiated from the harpischord. But this is not to say the air modes are unimportant; the presence of the air can and does affect the behavior of the soundboard.

The precise interplay of air and wood is not well understood, although we have enough information to put most of the pieces of the puzzle together. The strings do not directly communicate with the air cavity; only the motion of the soundboard can excite an air mode. But the air can indirectly affect this process by influencing the motion of the board. The soundboard may excite an air mode in the absence of a resonance of its own if the soundboard can move with enough amplitude to excite the air mode's hot spot.

The air modes can also influence the board by behaving as a load or by acting as an internal spring. In addition, physical coupling can occur if the mode shapes of the board and air are similar and if their resonant frequencies are close. Together the air and soundboard interact to suppress some frequencies and enhance others.

It should now be possible to answer the question, How does the harpsichord produce its swirling, distinctive sound? A player presses a key and sets a string into a complex pattern of vibration that consists of a fundamental and many partials. The string moves few molecules of air—certainly not enough to create pressure waves of a significant magnitude the ear could easily pick up. Just about none of the sound heard from a harpsichord comes directly from the vibrating strings. Rather, the strings transmit the energy to the soundboard via the bridge. The bridge acts as a selective filter, allowing only some frequencies of the vibrating string through to the soundboard. The board imposes its own characteristics on the frequencies it receives, suppressing some and enhancing others. The air in the cavity and the structural members also influence the sound by interacting with the soundboard.

But perhaps what most determines the harpsichord's sound are the numerous eigenmodes that we found during modal analysis experiments. The high modal density of the soundboard ensures that a large percentage of string partials will excite a board or an air mode, or both.

For instance, playing the harpsichord's lowest A, a note with a fundamental frequency of 55 hertz, excites soundboard resonances with the first three string partials, an air mode with the ninth partial, and both air and soundboard modes with the fourth, fifth, sixth and eighth partials. Thus, of the first 10 string partials of that low A, only the seventh and tenth fail to excite a resonance. The rich tone and generally uniform output of the harpsichord result directly from the large number of air and soundboard resonances excited by string partials.

There is one last source of coloration that gives the harpsichord its sound: the human ear. One of the characteristics of a good harpsichord is its strong bass. But the fundamental of a bass string is not particularly loud. If it were, the string would be vibrating with great amplitude, slapping against the soundboard and the other strings. How, then, does the ear perceive a distinctive, powerful bass?

The answer lies in the psychophysiological phenomenon called heterodyning, a useful term borrowed from electrical engineering. Bass strings have a rich structure of prominent partials. (Treble strings appear to oscillate with fewer partials than bass strings because most of the high-frequency partials lie beyond human hearing.) The brain uses these partials to identify the bass notes of the harpsichord.

Take as an example the low G on the harpsichord, with a frequency of about 50 hertz. Although the fundamental is physically present in the vibrating string, it is a weak component of the collection of frequencies that reaches the ear. The brain, however, recognizes that the partials near 100, 150, 200, 250 hertz and so on belong to the compact collection of closely related frequencies that make up the pitch of low G. It has no trouble supplying a 50-hertz frequency of its own. Heterodyning is the same process by which one can recognize a deep-voiced friend talking on the telephone, a device whose speaker is too small to vibrate strongly at the lowest frequencies of a voice.

The ear provides another sort of coloring as well. The auditory mechanism "hears" the high pitches of instruments very well, but in the bass register, it is quite inefficient. To compensate, musical instruments use far more energy to produce low-pitched sounds than high-pitched ones. For instance, a properly constructed harpsichord generates more power in the bass than in the treble. Interestingly, the net result is an even perception of sound level over the entire range of the instrument. One cannot help but view with wonder the exquisite balance between string, wood, air, ear and brain we call the "sound" of the harpsichord.

FURTHER READING

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THE HARPSICHORD OWNER'S GUIDE: A MANUAL FOR BUYERS AND OWNERS. Edward L. Kottick. University of North Carolina Press, 1987.

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IN THE BEGINNING...

by John Horgan, *staff writer*

Scientists are having a hard time agreeing on when, where and—most important—how life first emerged on the earth.

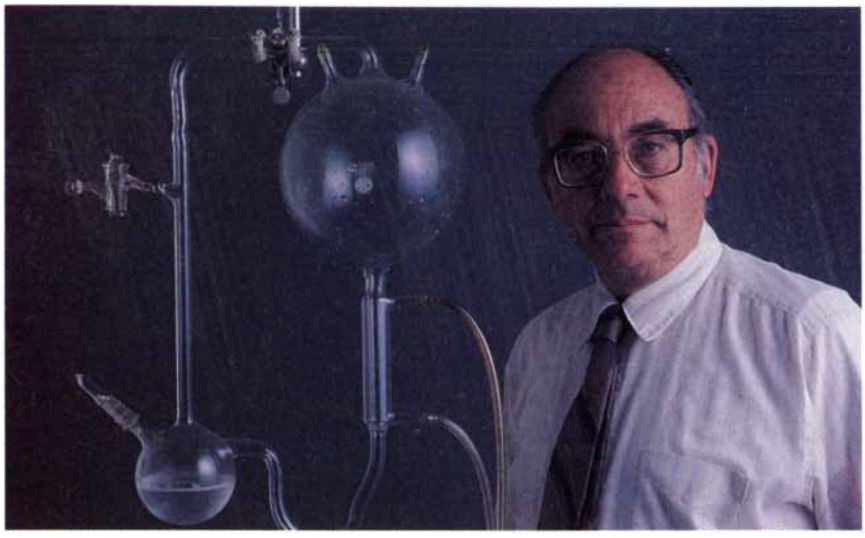
Thirty-eight years ago what is arguably the greatest mystery ever puzzled over by scientists—the origin of life—seemed virtually solved by a single, simple experiment. Stanley L. Miller, then a 23-year-old graduate student at the University of Chicago, re-created the primeval earth in a sealed glass apparatus. He filled it with a few liters of methane, ammonia and hydrogen (the atmosphere) and some water (the oceans). A spark-discharge device zapped the gases with simulated lightning, while a heating coil kept the water bubbling.

Within a few days, the water and glass were stained with a reddish goo. On analyzing the substance, Miller found to his delight that it was rich in amino acids. These organic compounds link up to form proteins, the basic stuff of life. Miller's results, which he published in a modest two-page article in *Science*, seemed to provide stunning evidence that life could arise out of simple chemical reactions in the "primordial soup."

Pundits speculated that scientists, like Mary Shelley's Dr. Frankenstein, would shortly conjure up living organisms in their laboratories and thereby demonstrate in detail how genesis unfolded. It hasn't worked out that way. "The problem of the origin of life has turned out to be much more difficult than I, and most other people, envisioned," says Miller, now a professor of chemistry at the University of California at San Diego.

Of course, there has been progress since 1953. That same year, in fact, James D. Watson and Francis H. C. Crick deciphered the structure of deoxyribonucleic acid (DNA), whose double-strand helix carries the information that cells need to build and organize proteins. Over the next few decades, experiments similar to Miller's demonstrated how the components of DNA (which are called nucleotides) as well as those of proteins could have been synthesized under prebiotic conditions. These organic compounds could have accumulated in various bodies of water: in some "warm little pond," as

SCIENTIFIC VERSION OF GENESIS begins with the condensation of the solar system from a cloud of gas and dust 4.5 billion years ago (a, b). *Organic chemicals could have been delivered by impacts* (c) *or synthesized in the atmosphere* (d), *tidal pools* (e) *or deep-sea hydrothermal vents* (f). *These chemicals combined to form more complex organic compounds, including proteins and nucleic acids* (g). *Impacts and a stifling greenhouse effect, caused by carbon dioxide spewed from volcanoes, could have rendered the earth's surface unfit for life until 3.8 billion years ago. But by 3.5 billion years ago—give or take about 300 million years—photosynthetic microbes resembling blue-green algae* (h) *had emerged. These primitive organisms sometimes formed dense mounds, called stromatolites, along the shores of shallow seas* (i).



STANLEY L. MILLER stands beside a replica of the apparatus he used in his 1953 experiment, which showed how amino acids could form on the primordial earth.

Charles Darwin once speculated in a letter, or in tidal pools or shallow seas.

Experiments in the early 1980s seemed to complete the picture. They revealed that ribonucleic acid, or RNA, a single-strand molecule that serves as DNA's helpmate in manufacturing proteins, might have the ability to make copies of itself without the assistance of enzymes. Some investigators concluded that the first organisms consisted of RNA and that an early "RNA world" had provided a bridge from simple chemistry to prototypes of the complex DNA-based cells found in modern organisms. According to the fossil record, such cells emerged within the first billion years after the earth had formed 4.5 billion years ago.

Although this scenario is already ensconced in textbooks, it has been seriously challenged of late. Tests of the RNA-world hypothesis have shown that RNA is difficult to synthesize in the conditions that probably prevailed when life originated and that the molecule cannot easily generate copies of itself.

To make matters worse, recent findings suggest that life arose in an environment far less hospitable than Miller's glass apparatus. The primordial atmosphere may not have contained methane and ammonia, as Miller had assumed, and so it may not have been nearly as favorable for the synthesis of organic compounds as his experiment suggested. Moreover, studies of craters on the moon indicate that the earth was being repeatedly laid waste by huge meteorites and comets. "It looks like life began not in a warm little pond but in a raging tempest," says Christopher P. McKay, a space scientist at the NASA Ames Research Center in California.

As the old paradigm has wobbled, many other theories—some brand-new and some recycled—have been put forward. Observations of organic compounds in meteorites and comets have led to speculation that the raw materials for life fell to the earth from outer space. The most extreme versions of this idea posit that not only inanimate organic compounds but also full-fledged organisms arrived from space. Some researchers, while holding that life arose on the earth, nonetheless think the best hope for understanding that event is to add another data point—that is, to find life elsewhere, on Mars, perhaps, or even in another solar system.

Others contend that life began not in deep space or in water near the surface of the earth but in hydrothermal vents, or hot springs, at the bottom of the oceans. Advocates argue that these vents could have provided the protection and steady flow of energy and nutrients needed to make matter animate. Perhaps the latest theory—and the most promising, in the eyes of some veteran origin-of-life researchers—comes from a German lawyer who speculates about genesis as a hobby. He proposes that life began as a gummy film on the surface of iron pyrite: fool's gold.

None of these approaches has gained enough support to qualify as a new paradigm. On the other hand, none has been ruled out. That bothers Miller, who is known as both a rigorous experimentalist and a bit of a curmudgeon. Some theories, he asserts, do not merit serious attention. He calls the organic-matter-from-space concept "a loser," the vent hypothesis "garbage" and the pyrite theory "paper chemistry." Such work, he grumbles, perpetuates the reputation of the origin-of-life field as being on the fringe of science and not worthy of serious pursuit.

Others, while agreeing that all theories have weaknesses, view the ferment more favorably. "I'm excited," says James P. Ferris, a chemist at Rensselaer Polytechnic Institute and editor of the journal *Origins of Life and Evolution of the Biosphere*. "We have all sorts of new ingredients in the pot." Sooner or later, Ferris suggests, a convincing explanation of genesis is bound to come crawling out.

Making a 747

Some scientists have argued that, given enough time, even apparently miraculous events become possible—such as the spontaneous emergence of a single-cell organism from the random couplings of chemicals. Yet Fred Hoyle, the iconoclastic British astronomer, has said such an occurrence is about as likely as the assemblage of a 747 by a tornado whirling through a junkyard.

Most researchers agree with Hoyle on this point (although on little else). The one belief almost everyone shares is that matter quickened through a succession of steps, none of which is wildly improbable. Like much of biology, this view dates back to Darwin, who conjectured that life began when chemicals stimulated by heat, light or electricity started reacting with one another and generating organic compounds of ever greater complexity. (Darwin also offered an explanation of why we do not observe life leaping from inanimate ooze today: any fledgling organisms, he wrote, would now be "instantly devoured or absorbed" by modern ones.)

The current version of genesis held by Miller and others is also couched in Darwinian terms. Life began, they say, when some compound or class of compounds developed the ability to copy itself in such a way that it occasionally made heritable "mistakes." These mistakes sometimes produced generations of molecules that could replicate more efficiently than their predecessors. Voilà: evolution, and so life.

For a period after Miller's experiment, proteins seemed to be the most likely candidates for the original self-replicating molecules, since they were thought to be capable of reproducing and organizing themselves. Beginning in the late 1950s, Sidney W. Fox, who is now at Southern Illinois University, performed experiments that provided even more support for this view. By repeatedly heating amino acids and dissolving them in water, he induced them to

coagulate into tiny spheres composed of short protein strands.

Fox argued then—and continues to do so—that these "proteinoids" represent the first cells, but his work has fallen out of favor among many scientists. Once proteinoids are formed, "that's it," says Gerald F. Joyce of the Research Institute of Scripps Clinic. "They can't reproduce or evolve." Even so, various other researchers, notably Cyril A. Ponnamperuma of the University of Maryland at College Park, have picked up where Fox left off, trying to develop proteins that can assemble themselves and reproduce without assistance from nucleic acids.

Chicken or Egg?

Many investigators now consider nucleic acids to be much more plausible candidates for the first self-replicating molecules. The work of Watson and Crick and others has shown that proteins are formed according to the instructions coded in DNA. But there is a hitch. DNA cannot do its work, including forming more DNA, without the help of catalytic proteins, or enzymes. In short, proteins cannot form without DNA, but neither can DNA form without proteins. To those pondering the origin of life, it is a classic chicken-and-egg problem: Which came first, proteins or DNA?

Experiments performed in the early 1980s by molecular biologists Thomas R. Cech of the University of Colorado at Boulder and Sidney Altman of Yale University seemed to provide an answer—in the form of RNA. Researchers had previously speculated that RNA might be the first self-replicating molecule, but no one had shown how it could efficiently replicate itself without the help of enzymes. Cech and Altman discovered that certain types of RNA could act as their own enzymes, snipping themselves in two and splicing themselves back together again.

The finding, which earned Cech and Altman Nobel prizes in 1989, was quickly seized on by origin-of-life researchers. They realized that if RNA could act as an enzyme then it might also be able to replicate itself without help from proteins. RNA could serve as both gene and catalyst, egg and chicken.

Walter Gilbert, a biologist at Harvard University, coined the term "RNA world" in 1986 and remains an enthusiastic advocate of the theory. In his view, the first organisms consisted of simple self-replicating RNA molecules. As they evolved, they learned to synthesize proteins that could help them replicate faster and lipids that could form a cell wall. Finally, the RNA organisms gave rise to DNA, which served as a more reliable repository of genetic information.

Biologists have had some success reproducing various acts of this molecular drama in the laboratory. For example, Jack W. Szostak and other workers at Massachusetts General Hospital have built customized RNA molecules that can act as enzymes—cutting and pasting together molecules, including themselves—repeatedly. RNA "enzymes" had previously been limited to single performances. Szostak is also trying to show how such RNAs could have become encapsulated in a cell-like membrane.

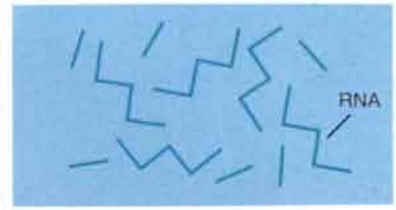
Other investigators, notably Manfred Eigen of the Max Planck Institute for Biophysical Chemistry in Göttingen, have examined what is thought to be a later stage in RNA's ascension. Their experiments show that RNA—with the encouragement of enzymes and other inducements supplied by the experimenter—can adapt and evolve. This effect, which is called directed evolution, has been hailed as a potentially powerful method for generating new biological compounds.

But as researchers continue to examine the RNA-world concept closely, more problems emerge. How did RNA arise initially? RNA and its components are difficult to synthesize in a laboratory under the best of conditions, much less under plausible prebiotic ones. For example, the process by which one creates the sugar ribose, a key ingredient of RNA, also yields a host of other sugars that would inhibit RNA synthesis. Moreover, no one has yet come up with a satisfactory explanation of how phosphorus, which is a relatively rare substance in nature, became such a crucial ingredient in RNA (and DNA).

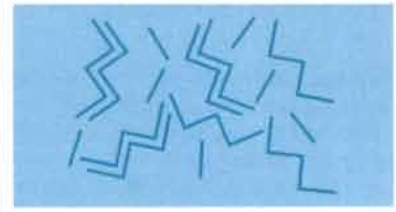
Once RNA is synthesized, it can make new copies of itself only with a great deal of help from the scientist, says Joyce of the Scripps Clinic, an RNA specialist. "It is an inept molecule," he explains, "especially when compared with proteins." Leslie E. Orgel of the Salk Institute for Biological Studies, who has probably done more research exploring the RNA-world scenario than any other scientist, concurs with Joyce. Experiments simulating the early stages of the RNA world are too complicated to represent plausible scenarios for the origin of life, Orgel says. "You have to get an awful lot of things right and nothing wrong," he adds.

Orgel has come to the conclusion that some simpler—and possibly quite dissimilar—molecule may well have paved the way for RNA. Identifying this

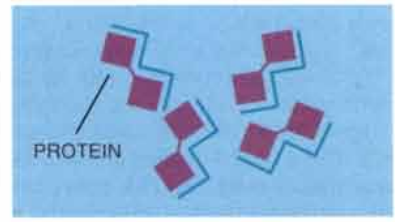
EVOLUTION VIA THE RNA WORLD



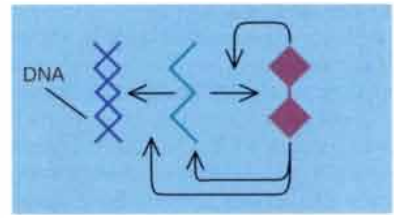
RNA forms from ribose and other organic compounds.



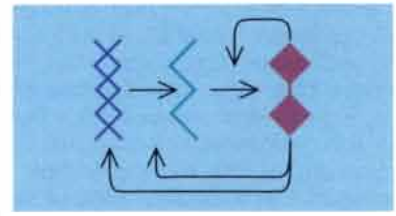
As RNA molecules evolve, they "learn" to copy themselves.



RNA molecules begin to synthesize proteins that can serve as catalysts.



The proteins help the RNA replicate and synthesize proteins more efficiently. They also help the RNA make double-strand versions of itself that evolve into DNA.



DNA takes over. It uses RNA to make proteins, which in turn help DNA make copies of itself and transfer its genetic information to RNA.

3.5-BILLION-YEAR-OLD FOSSILS include a string of cells resembling cyanobacteria, or blue-green algae (*left*), and a stromatolite (*center*) from sites in Western Australia. Stromatolites can still be found in Australia (*right*) and elsewhere.

compound will not be easy. Nucleic acid chemistry, Orgel points out, rests on a broad foundation of knowledge, and once researchers venture away from this realm, they will be starting virtually from scratch. "That would be a major business," he says.

Some researchers have already wandered into the unknown. Last summer a group led by Julius Rebek, Jr., a chemist at the Massachusetts Institute of Technology, created a stir by announcing that it had created a synthetic organic molecule that could replicate itself. The molecule, called amino adenosine triacid ester (AATE), consists of two components that chemically resemble both proteins and nucleic acids. AATE molecules, when placed in a solution of chloroform stocked with the components, serve as templates for the formation of new AATEs.

Rebek's experiments have two drawbacks, according to Joyce: they only replicate in highly artificial, unnatural conditions, and, even more important, they reproduce too accurately. Without mutation, the molecules cannot evolve in the Darwinian sense. Orgel agrees. "What Rebek has done is very clever," he says, "but I don't see its relevance to the origin of life."

Indeed, although recent reports in the lay press have suggested that Szostak, Rebek and others are on the verge of creating "life in a test tube" (a story about Rebek in *Discover* magazine was headlined: "Yikes! It's Al-i-i-i-i-ve!"), that goal seems more distant than ever to some observers. "The simplest bacterium is so damn complicated from the point of view of a chemist that it is almost impossible to imagine how it happened," says Harold P. Klein of Santa Clara University, chairman of a National Academy of Sciences committee that recently reviewed origin-of-life research. (Its conclusion: much more research is needed.)

Even if scientists do create something with lifelike properties in the laboratory, they must still wonder: Is that how it happened in the first place? Answering that question will be extraordinarily difficult, since plate tectonics, vulcanism and erosion have obliterated most traces of the earth's first billion years. To estimate the age of the earth, for example, investigators must turn to meteorites, which are presumed to be relics of the era when the solar system condensed from a cloud of gas and dust. The degree of radioactive decay observed in meteorites has indicated that they, and so the earth, are roughly 4.5 billion years old.

Scum of the Earth

Of course, establishing the conditions under which life emerged requires knowing when it emerged. Scientists once thought that billions of years passed before the dead earth quickened. The reason is that the fossil record of multicellular creatures—from trilobites to Neanderthals—extends back only 600 million years before the present. (*Homo sapiens* appeared less than a million years ago.) Over the past few decades, however, paleontologists have realized that before multicellular organisms came along the earth was populated for billions of years by such simple creatures as algae—or "pond scum," as J. William Schopf of the University of California at Los Angeles, an authority on early fossils, puts it.

Schopf and others have accumulated what they believe is unequivocal evidence that life existed at least 3.5 billion years ago. The evidence includes two sets of fossils from sites in Australia and South Africa whose age has been established through radioactive dating. One set consists of lumpy, greenish-brown rocks that were once stromatolites, dense mounds of microbes that still grow in warm, shallow water in several locations around the world. The other fossils show the microscopic imprints of strings of cells resembling modern cyanobacteria, also called blue-green algae. Schopf says the ancient organisms, like cyanobacteria, probably employed photosynthesis and gave off oxygen as a by-product.

At least one worker, Manfred Schidlowski of the Max Planck Institute for Chemistry in Mainz, thinks he has found evidence that photosynthetic organisms existed even earlier. The evidence comes from 3.8-billion-year-old, partially melted sedimentary rocks from Isua, Greenland. These are the oldest terrestrial rocks with much of a story to tell. (The absolute record-holders, 4.2-billion-year-old zircon crystals from Australia, are mute on the subject of the past.) The fact that the Isua rocks are sedimentary reveals that liquid water, a prerequisite for life, was present then. According to Schidlowski, the carbon content of the rocks also indicates that they were contaminated by photosynthetic organisms, which prefer certain isotopes of carbon.

This attempt to extend the fossil record further back into time has met with some skepticism. David J. Des Marais of NASA Ames says the carbon signature in the Isua rocks is simply too faint to interpret. Roger Buick, an Australian paleontologist now at Harvard, says this skepticism should also apply to the 3.5-billion-year-old stromatolites and microfossils, which unlike the Isua rocks are widely accepted as being of biological origin. The stromatolites could be sediments distorted by geologic processes, Buick asserts, and the microfossils look to him like "little streaks of [excrement]." He calls them "dubio-fossils." Buick argues that fossils clearly showing cellular structure date back only to 3.1 or 3.2 billion years ago.

Other experts on so-called Archaean fossils, including Donald R. Lowe of Stanford University, think Buick, and perhaps even Des Marais, is being too skeptical. Although individual fossils are ambiguous, Lowe says, in their sum

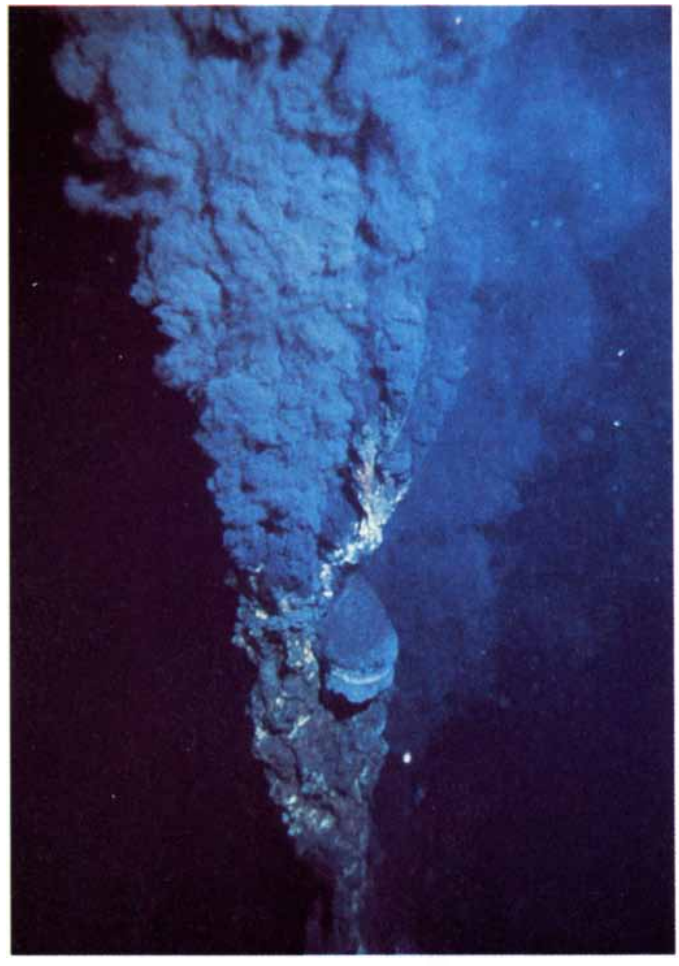
they suggest that life was "extensive, diverse and sophisticated" 3.5 billion years ago and was probably well under way before the 3.8-billion-year mark. If correct, this scenario implies that life evolved and survived under unpleasant—and periodically even hellish—circumstances.

By analyzing craters on the moon, which form a Braille-like record of the rate of impacts in the young solar system, groups led by geophysicists David J. Stevenson of the California Institute of Technology and Norman H. Sleep of Stanford independently concluded some two years ago that meteorites and comets smashing into the earth could have deterred the emergence of life for hundreds of millions of years. Many of the projectiles would have been much larger than the 10-kilometer-wide object that some scientists believe killed off the dinosaurs at the boundary between the Cretaceous and Tertiary epochs 65 million years ago.

The impacts of such large objects, Sleep says, would have generated enough heat to boil the surface of the oceans—and perhaps to vaporize them entirely. The collisions also would have thrown huge clouds of dust and molten rock into the atmosphere. The implication of these calculations is dramatic: at the very least, the impacts would have destroyed incipient life on land or anywhere near the surface of the oceans until 3.8 billion years ago. Life dependent on photosynthesis would have been particularly vulnerable.

It seems, moreover, that the atmosphere's composition during this period may not have favored the synthesis of organic compounds as much as had been thought. The traditional view was elucidated in the early 1950s by Harold C. Urey, a Nobel laureate in chemistry at the University of Chicago. He proposed that the atmosphere was reducing: rich in hydrogen-based gases such as methane and ammonia, which are abundant on Saturn, Jupiter and Uranus. It was Urey's work that inspired Miller, a student of Urey's, to conduct his 1953 experiment.

Yet over the past decade or so, doubts have grown about Urey and Miller's assumptions regarding the atmosphere. Laboratory experiments and computerized reconstructions of the atmosphere by James C. G. Walker of the University of Michigan at Ann Arbor and others suggest that ultraviolet radiation from the sun, which today is blocked by atmospheric ozone, would have destroyed hydrogen-based molecules in the atmosphere. Free hydrogen would have escaped into space.



DEEP-SEA HYDROTHERMAL VENTS, which were found in the late 1970s, may have provided nutrients and a protected environment for the first organisms, according to some researchers.

The major component of the atmosphere, these findings suggest, was carbon dioxide and nitrogen spewed out by volcanoes. Such an atmosphere would not have been conducive to the synthesis of amino acids and other precursors of life. According to recent calculations by James F. Kasting of Pennsylvania State University, the carbon dioxide might also have created a greenhouse effect so extreme that temperatures at the earth's surface rose nearly to the boiling point of water.

The reducing-atmosphere model still has its defenders. Miller, for one, points out that smoke and clouds could have shielded the delicate hydrogen-based gases from ultraviolet radiation. "You have a chorus of people with mathematical models saying there is no methane," he says, "but they have absolutely no real evidence." A recent report from researchers at Yokohama National University supports Miller's position. The Japanese scientists argue that solar particles and cosmic rays could have spurred synthesis of free hydrogen—and consequently methane and ammonia—by breaking up water molecules.

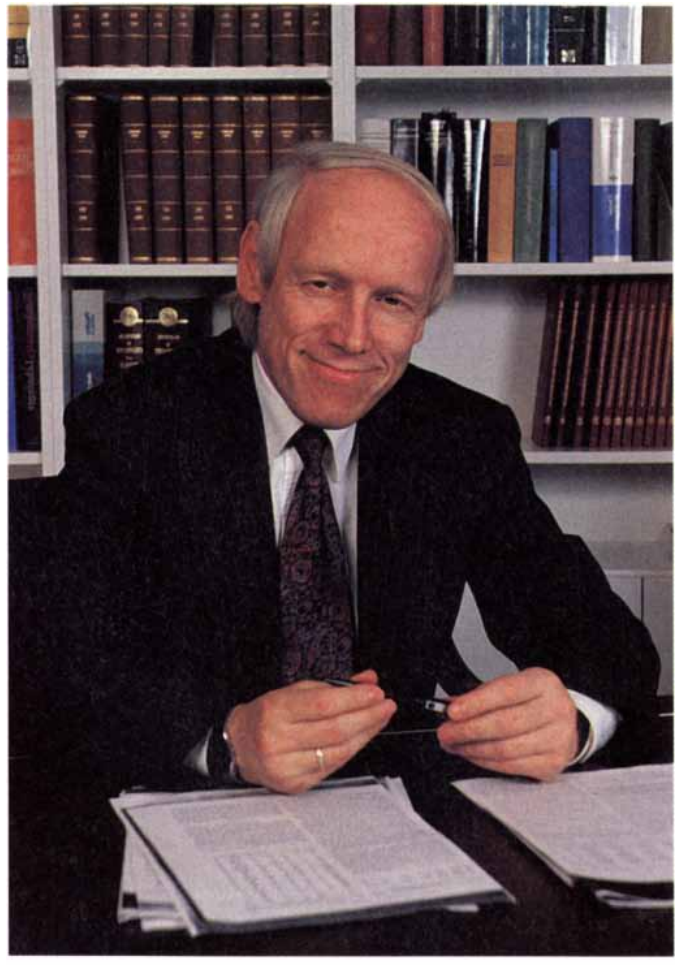
Nevertheless, the research on impacts and the atmosphere—combined with the belief that primitive organisms existed 3.8 billion years ago—has led some investigators to suspect that life was incubated not in turbid tidal pools at the earth's surface but in the ocean depths. In the late 1970s scientists discovered several hydrothermal vents on the sea floor near the Galápagos Islands. The vents support thriving communities of life—including tube worms, clams and bacteria, whose primary source of energy is not light but sulfur compounds emitted by the vents. Dozens of similar vents have been located since then, generally near the underwater ridges that form at the seam between two tectonic plates.

A major proponent of vents as the wombs of life is John B. Corliss of NASA's Goddard Space Flight Center, who was a member of the team that discovered one of the first vents. Corliss argues that vents could have supplied the energy and nutrients needed to create and then sustain life. The interior of the vents, he says, would also be protected from the ill effects of all but the biggest extraterrestrial impacts—or those that scored a direct hit. (Corliss points out that modern vent species, which live in the comparatively chilly waters outside vents, are probably late arrivals rather than direct descendants of the original vent inhabitants.)

An important piece of evidence for

the vent hypothesis comes from studies of single-cell organisms conducted by Carl R. Woese of the University of Illinois at Urbana-Champaign. By comparing the genetic makeup of such organisms, Woese has identified a class of microbes—which he calls archaebacteria—that seem to have undergone less evolutionary change than any other living species. All archaebacteria prefer hot environments; some can survive temperatures ranging as high as 120 degrees Celsius (248 degrees Fahrenheit). Certain species also prefer an oxygenless, acidic environment with a steady supply of sulfur—precisely those conditions prevailing at hydrothermal vents.

Norman R. Pace, a biologist at Indiana University, finds the vent theory persuasive. He pictures the crust of the primordial earth as a "thin, roiling scum" of rock pocked by myriad hydrothermal vents. Yet unlike Corliss, who insists that life originated at the vents, Pace says the first organisms may have been spawned elsewhere—perhaps at or near the surface of the earth during a lull between impacts—and spread later to the relative security of deep-sea vents. Subsequent impacts may then have destroyed all organisms except those hidden in the vents. These hydrothermal organisms, although not the first to exist on the earth, would nevertheless be the ancestors of all existing life. Pace believes even today vast communities of bacteria may dwell in networks of geothermally heated cracks and caverns beneath the mid-ocean ridges.



PATENTED PROCESS? Günter Wächtershäuser, a German patent attorney, has produced a new theory on the origin of life.

Sulfur Stories

Miller does not like vents—at least, not as the original seats of life. He notes that modern vents seem to be short-lived, lasting only for a few decades before they are plugged up. Moreover, he and Jeffrey L. Bada, who is also at the University of California at San Diego, have done experiments that suggest the superheated water inside the vents—which sometimes exceeds 300 degrees Celsius (572 degrees Fahrenheit)—would destroy rather than create complex organic compounds. If the surface of the earth is a frying pan, Miller says, a hydrothermal vent is the fire.

The vent hypothesis has nonetheless bolstered the standing of three theories—two of them new and one a bit shopworn—that offer alternatives to (or precursors of) RNA. The latest and most unusual theory of this type comes from Günter Wächtershäuser, who is himself an unusual theorist. A practicing attorney, Wächtershäuser founded and oversees a firm in Munich specializing in patent law. Before entering the legal profession, however, he gained a doctorate in organic chemistry and an abiding interest in the origin of life.

Once content to be simply an observer, Wächtershäuser started developing his own ideas about five years ago. Whereas most investigators have assumed that life began when some relatively simple compound began to make copies of itself in a solution, he speculated that life started as a metabolic process—a cyclic chemical reaction that is driven by some source of energy—taking place on the surface of a solid.

These ideas have precedents, but Wächtershäuser's proposal is unique in its details. It calls for a very specific solid surface: one made of pyrite, or fool's gold, a metallic mineral consisting of one iron and two sulfur molecules. Pyrite has been found at vents—not surprisingly, since it is common worldwide. According to Wächtershäuser, pyrite also offers a positively charged surface to which simple organic compounds can become bonded; the continuing formation of pyrite from iron and sulfur also yields energy—in the form of electrons—that induces the organic compounds to react with one another and grow in complexity.

The first cell, he conjectures, might have been a grain of pyrite enclosed in a membrane of organic compounds. The cell could have reproduced if the pyrite grain grew a new crystalline "bud" that became encapsulated in its own membrane and broke free.

Wächtershäuser has set forth his ideas in such peer-reviewed journals as the *Proceedings of the National Academy of Sciences, Microbiology Reviews* and *Nature*. Experiments by a group at the University of Regensburg in Germany also provide some support for his view of pyrite as a "battery." But Wächtershäuser himself admits that his theory is for the most part still "pure speculation."

Nevertheless, his ideas have captivated Pace, Woese and the German historian of science Karl Popper, among others. Pace says Wächtershäuser's metabolism-first, surface-based model could render obsolete the old replication-first, solution-based paradigm.

Others are less than awed. Joyce suspects that Wächtershäuser's legal skills may have helped him win more acceptance for his theory than it deserves. "He's an excellent advocate for his case," Joyce observes. But he admits he is intrigued by the parallel between Wächtershäuser and another German

who practiced science while holding a job involving patents: Albert Einstein. "Given the precedent," Joyce remarks dryly, "I guess we'd better take him seriously."

A model that bears some similarity to Wächtershäuser's has been proposed by Christian R. de Duve, a professor emeritus at the Rockefeller University, who won a Nobel Prize in 1974 for his work on cellular structure. De Duve's theory, which he has set forth in a new book, *Blueprint for a Cell*, revolves around sulfur-based compounds called thioesters. Thioesters play a critical role in cellular metabolism, and various studies have suggested that they may have been a source of energy in primitive cells.

De Duve proposes that thioesters in the primordial ooze could have triggered a cascade of chemical reactions resembling those occurring in modern cellular metabolism. The reactions would have been catalyzed by "proto-enzymes," also formed from thioesters. The reactions would eventually result in the synthesis of ribonucleic acids, thereby ushering in the RNA world. The synthesis of thioesters requires a hot, acidic environment, which de Duve says could be provided by hydrothermal vents.

"I'd love to see the experimental evidence," Miller says. Yet he acknowledges that experimentalists like himself may have neglected sulfur-based chemistry for a reason that is not purely scientific: "Sulfur smells. It would smell up your whole lab."

Feat of Clay

A. G. Cairns-Smith, a chemist at the University of Glasgow, says he has a good reason to doubt de Duve's theory: it depends on a proposal, advanced by himself and David C. Mauzerall of Rockefeller, which suggests how a reaction involving iron and water might have enriched the primordial atmosphere with hydrogen. "What de Duve neglected to say," Cairns-Smith notes, "is that this process makes the oceans *less* suited for the synthesis of organic molecules."

For more than a decade, Cairns-Smith has been pushing his own hypothesis. Like Wächtershäuser, he proposes that life arose on a solid substrate that occurs in vents and almost everywhere else, but he prefers crystalline clays to pyrite. All crystals consist of self-replicating units, Cairns-Smith points out, but clay crystals have enough complexity to mutate and evolve in a lifelike way. Some clays might have become still better breeders by developing the

GENESIS IN SILICON

Although the traditional way to test theories of genesis involves mixing real chemicals in real test tubes, a number of researchers are trying to re-create creation in a computer. Stuart A. Kauffman, a biologist who shuttles between the University of Pennsylvania and the Sante Fe Institute in New Mexico, is a pioneer of this "artificial life" approach.

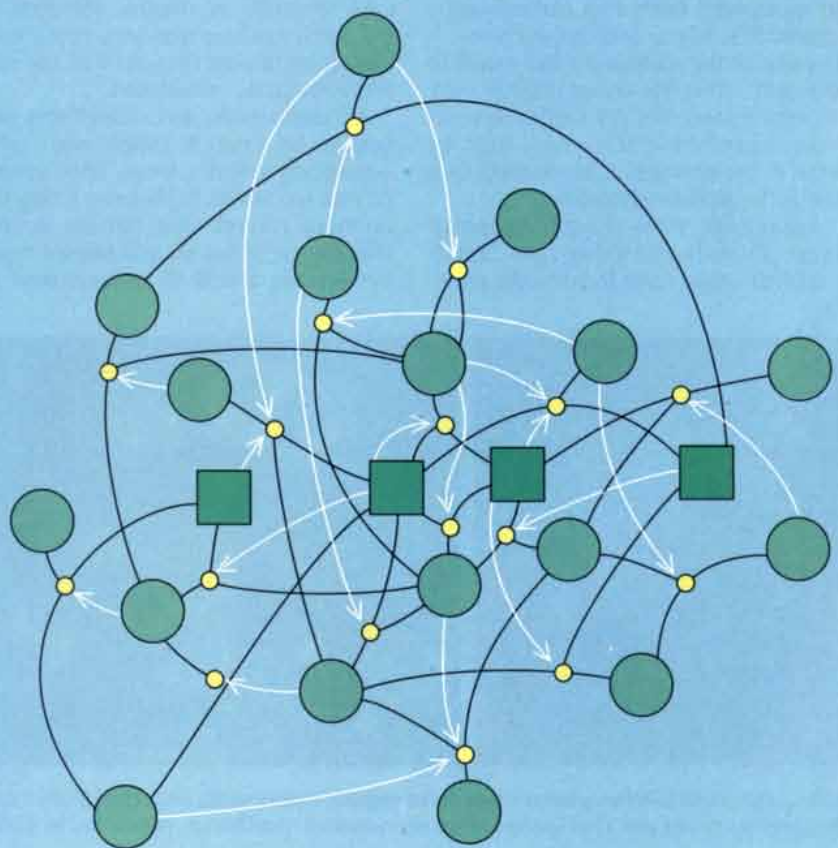
Kauffman has long suspected that the origin of life may depend on some fundamental principle that causes order to emerge from apparently random, hopelessly complicated chemical interactions. To test this theory, he and his colleagues at the Santa Fe Institute have performed computer simulations of interactions between sets of generic polymers with generic catalytic activity.

In a simplified representation of one simulation, simple monomers (*squares*) with some catalytic ability (*white arrows*) trigger a cascade of chemical reactions (*black lines and yellow circles*) between polymers (*green circles*), which then catalyze still more reactions.

According to Kauffman, the simulations demonstrate that a system supplied with a sufficient number of such polymers will undergo a "phase transition" that causes it to become "auto-catalytic." That is, the system will spontaneously begin generating polymers of ever greater complexity and catalytic capability.

Kauffman says he is absolutely convinced that a process like this—rather than the fortuitous formation of a single type of molecule with the ability to evolve—led to life. Asked if he has any test-tube results to back up his computer simulations, Kauffman replies: "No one has done this in pots, but I'm sure I'm right."

Test-tube traditionalists scoff. "Running equations through a computer does not constitute an experiment," sniffs Stanley L. Miller of the University of California at San Diego. Gerald Joyce of the Research Institute of Scripps Clinic, another test-tube type, is also skeptical. But he points out that artificial-intelligence research—once sneered at by more conventional students of the human brain—has begun to make important contributions to neurobiology. "If artificial life can someday do that for the origin of life," Joyce says, "that would be fantastic."



ability to attract or synthesize organic compounds—such as nucleic acids or proteins. Eventually, the organic compounds would become sophisticated enough to begin replicating and evolving on their own.

Unlike some origin-of-life theorists, Cairns-Smith cheerfully admits the failings of his pet hypothesis: no one has been able to coax clay into something resembling evolution in a laboratory; nor has anyone found anything resembling a clay-based organism in nature. Yet he argues that no theory requiring organic compounds to organize and replicate without assistance is likely to fare any better. "Organic molecules are too wiggly to work," he says.

Space Invaders

There is one other way out of this frustrating theoretical impasse. If neither the atmosphere nor vents provide a likely locale for the synthesis of complex organic compounds, maybe they were imported from somewhere else: outer space. Juan Oró of the University of Houston raised this possibility as early as the 1960s. The idea has received more attention since then as astronomers have detected the telltale spectra of an ever greater assortment of organic compounds in space, both enveloping individual stars and drifting in the void between stars.

Amino acids have also been found in meteorites known as carbonaceous chondrites, which account for about 5 percent of the meteorites that crash to the earth. Observations of Halley's comet, which passed by the earth five years ago, suggested that comets may be even richer in organic compounds than the carbonaceous chondrites.

Chondrites even contain hydrocarbons, alcohols and other fatty chemicals that could have formed the membranes that protected primitive cells. David W. Deamer, a biochemist at the University of California at Davis, has produced spherical membranes, or vesicles, with compounds he obtained from a meteorite that fell near Murchison, Australia, in 1969. These vesicles, he says, may have provided an environment within which amino acids, nucleotides or other organic compounds could undergo the transformations necessary for life to begin.

The notion that impacts could have set the stage for life as well as delaying its entrance gained ground in 1989. The cause was the discovery of amino acids just above and below a layer of clay deposited at the Cretaceous-Tertiary boundary. Bada and Meixun Zhao, also at San Diego, determined that the amino acids were nonbiological types found previously only in meteorites. Their report seemed to support the theory that an impact had killed the dinosaurs—and also to show that large impacts might fertilize the earth with organic compounds.

But questions remained: Why were the amino acids found above and below the Cretaceous-Tertiary layer and not within it? And how did the amino acids survive the enormous heat created by the impact? Calculations by Christopher F. Chyba, a planetary scientist at Cornell University, and others suggested that any extraterrestrial object large enough to supply significant amounts of organic material to the earth would generate so much heat during its impact that most of the material would be incinerated.

An explanation was offered last November by Kevin J. Zahnle and David Grinspoon of NASA Ames. They asserted that the amino acids came from one or more comets that did not smash into the earth but simply passed nearby—leaving a trail of organic dust in their wakes—before and after the Cretaceous-Tertiary impact. In this way, they assert, comets could also have sprinkled the earth with organic compounds during its very early history.

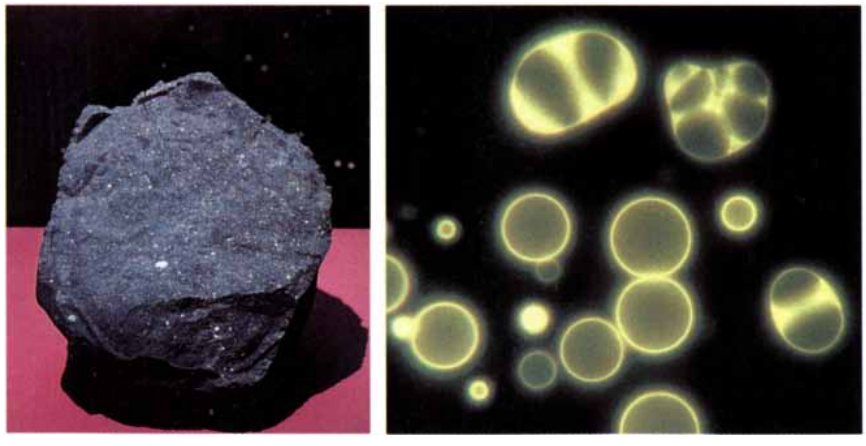
Cornell's Chyba has suggested some other ways in which impacts might contribute some of the raw materials needed for life. The heat and shock waves from an impact might initiate chemical reactions in the atmosphere that synthesize organic compounds, he says. The extraterrestrial object might also break up into pieces light enough to be decelerated by the atmosphere and so to land relatively intact.

Others find the impact scenarios inherently implausible. "It's too much like manna from heaven," says Sherwood Chang of NASA Ames, an authority on extraterrestrial organic compounds. Investigators should spend more effort exploring how organic compounds could be synthesized on the earth, Chang asserts, before assuming that impacts must have done the job. Theories giving impacts a role in genesis "are very trendy right now," he adds, "but they are also very speculative."

The most extreme version of the manna-from-space concept is panspermia. This theory was proposed at the end of the last century by the Swedish chemist Svante A. Arrhenius, who asserted that microbes floating throughout the universe served as the "seeds of life" on earth. In modern times Hoyle and a former student, the Sri Lankan astronomer N. Chandra Wickramasinghe (who are also known for their attacks on the big bang theory in cosmology), continue to promulgate this notion, even arguing that extraterrestrial microbes are the cause of influenza, AIDS and other diseases.

Most scientists utterly reject these assertions, declaring that microbes have never been found in space and are unlikely to be, since space is so inimical to life. Yet experiments done by J. Mayo Greenberg, an astrophysicist at the University of Leiden in the Netherlands, have actually lent panspermia some credence. Greenberg concluded that a naked cell could survive for hundreds of years in space—and for as many as 10 million years if it is protected from radiation by a thin shell of ice.

Greenberg notes that it is still difficult to imagine how organisms could escape other planets or descend to this one intact. Like most other scientists, he believes life was created on the earth. Nevertheless, he says the panspermia hypothesis, while perhaps improbable and certainly distasteful to many scientists, cannot be ruled out on the basis of his experiments.



CELL-LIKE VESICLES have been made from organic compounds extracted from a carbonaceous chondrite that landed near the town of Murchison, Australia, in 1969.

ANTARCTIC LAKE harbors thriving communities of microbes beneath its frozen surface. Such findings have raised hopes that Mars, which like the Antarctic is extremely cold and dry and is thought to have frozen water, could support life.

About a decade ago Orgel and Crick managed to provoke the public and their colleagues by speculating that the seeds of life were sent to the earth in a spaceship by intelligent beings living on another planet. Orgel says the proposal, which is known as directed panspermia, was "sort of a joke." But he notes that it had a serious intent: to point out the inadequacy of all explanations of terrestrial genesis. As Crick once wrote: "The origin of life appears to be almost a miracle, so many are the conditions which would have had to be satisfied to get it going."

Are We Alone?

Yet other scientists think that genesis, far from being miraculous, may be a rather common phenomenon. Indeed, the apparent rapidity with which life arose on the earth and the abundance of organic molecules throughout space suggest that life may also have occurred elsewhere in the universe, says John D. Rummell, who manages NASA's so-called exobiology program. Finding evidence of such life, he points out, in addition to being an epochal event in its own right, could illuminate earthly beginnings.

NASA is expanding its search-for-extraterrestrial-intelligence, or SETI, program, which monitors the electromagnetic spectrum for signals that might be generated by another civilization. Over the next decade, NASA investigators will survey radio signals coming from the entire sky, while focusing on some 700 stars that are relatively close to the earth and are thought to be possible locations for planets. NASA has developed equipment that enables a single radio telescope to monitor billions of channels simultaneously and bring suspect signals automatically to the attention of scientists.

Researchers are also investigating anew the possibility that life arose on our closest neighbor: Mars. NASA researcher McKay says that Mars and the earth were much alike during their first few hundred million years. Observations of old riverbeds and mud channels suggest that water once flowed on the red planet. This fact, McKay says, suggests that Mars was once blanketed in a warm carbon dioxide atmosphere.

The *Viking* spacecraft, which landed on Mars in the 1970s, found no traces of life. Yet McKay says the possibility that a future mission will find such evidence—either in fossilized form or still living—has been bolstered by discoveries of microbes in unlikely places on the earth. McKay and other workers have found dense microbial mats on the bottom of perennially frozen lakes in Antarctica, whose frigid, dry climate resembles that of Mars. Bacteria have also been found in sedimentary rock and oil deposits thousands of feet below the surface of the earth, in salt deposits and, of course, at deep-sea vents.

Mars should be ideal for fossil hunting, according to McKay. "It's been in a freezer for four billion years," he says, "and it has no plate tectonics. It's a paleontologist's dream." He acknowledges that Mars lacks one potentially significant terrestrial feature: a large moon. "If you assume that life evolved in tidal pools," he says, "then the Mars analogy fails." McKay believes finding extraterrestrial life would set origin-of-life research on solid observational ground, just as the 1965 discovery of microwave radiation pervading the universe legitimized cosmology: "We need something like the cosmic microwave background to make us respectable."

Miller, who after almost four decades is still in hard pursuit of life's biggest secret, agrees that the field needs a dramatic finding to constrain the rampant speculation. But he thinks such a discovery is more likely to emerge from earthbound laboratories. What the field needs now, Miller comments, is not more theories or far-flung searches for alien life but more experiments. "I come up with a dozen ideas a day, and I usually discard"—he reflects for a moment—"the whole dozen."

Does he ever entertain the possibility that genesis was a miracle not reproducible by mere humans? Not at all, Miller replies. "I think we just haven't learned the right tricks yet," he says. "When we find the answer, it will probably be so damned simple that we'll all say, 'Why didn't I think of that before?'"

Life in the Blood

Growth factors replenish the body's most important cells

National lab dilemma, transparent masking, feeling reality, market socialism

Blood cells are masters of proliferation. Each day in healthy bodies some 250 billion red cells replace those that have gone before. Much smaller populations of defensive white cells circulate steadily, awaiting immune system signals to reproduce quickly and attack invaders. Blood cell formation is one of the most important of all bodily functions. Yet the substances that control this complex process were unknown a decade ago.

Today blood cell growth factors are helping thousands of patients and soon will treat many more. So far more than a dozen such proteins have been identified. Some, known as colony-stimulating factors (CSFs), stimulate specific groups of cells, such as granulocytes, macrophages and monocytes, which destroy bacteria and viruses and remove dead and damaged cells. Others such as interleukin-3 (IL-3) and a newly discovered stem cell growth factor encourage growth and differentiation of many cell types. One growth factor, erythropoietin (EPO) is already being used to bolster the red cell supplies of kidney patients on dialysis. Emerging from the laboratory are other factors that have promise as therapies for bone marrow transplants, cancer and infectious diseases and as an adjunct to chemotherapy.

Growth factors have become the lifeblood of biotechnology companies such as Amgen, Immunex and Genetics Institute, Inc. Major pharmaceutical firms, including Schering-Plough, Upjohn, Hoffman–La Roche and Chugai, are also preparing to tap a market that by the year 2000 will be "well in excess of a billion dollars worldwide," declares Jeffrey W. Casdin, senior vice president for Oppenheimer & Co. in New York.

Amgen became the first company to bring a blood growth factor to the market, when in 1989 it won Food and Drug Administration approval for EPO to treat chronic renal failure. The Thousand Oaks, Calif., company has pulled in more than $300 million from the drug to date, despite a bitter patent dispute with Genetics Institute (GI) in Cambridge, Mass. GI also contends that it has dominating patent positions on IL-3 and GM-CSF (granulocyte-macrophage colony–stimulating factor), which it intends to defend aggressively.

It may have to soon. Two more blood cell growth factors received favorable reviews from an FDA advisory panel in mid-December of 1990 and are expected to come to market early in 1991. To help transplanted marrow get over the shock of being in a new body, Seattle's Immunex will market Leukine, its form of GM-CSF to promote engraftment. Amgen will begin selling G-CSF (granulocyte colony–stimulating factor), tradenamed Neupogen, to treat the most common and dangerous side effects of chemotherapy—the destruction of white blood cells that leaves patients prey to bacteria and viruses.

Meanwhile Genetics Institute is getting M-CSF (macrophage colony–stimulating factor) ready to grow. The company is conducting clinical trials of the substance to treat cancer, by itself and in combination with tumor-specific antibodies. Late this year it plans to test the protein against chronic fungal infections and as a cholesterol-lowering agent. Both GI and Cetus Corporation have cross-licensed their rights to M-CSF because of patent overlaps.

Still in the laboratory are a number of other growth factors, including a passel of interleukins, which stimulate early-stage white blood cells. One, dubbed IL-6, is being tested in combination with IL-3 to treat low platelet counts. IL-11 seems to stimulate early platelets and lymphocytes; IL-9 boosts *T* lymphocytes and red blood cells, and IL-7 *B* and *T* lymphocytes.

Scientists are still uncovering more growth factors—sometimes at the very same time. "It's common that people researching growth factors end up at the same end point simultaneously. Everyone clones different activities, and the gene turns out to be the same," observes Douglas E. Williams, director of experimental hematology at Immunex.

That was the case in October 1990, when three research groups reported yet another find. Amgen calls the substance stem cell growth factor, Immunex terms it MGF (mast cell growth factor) and Memorial Sloan-Kettering Cancer Center has dubbed it c-*kit* ligand. All may soon compromise and call it *steel* factor.

Stem cells, from their home in the bone marrow, give rise to a panoply of blood cell types. They are the most primitive cells known to exist in the body and quite rare. Only one stem cell is found among 100,000 other mature bone marrow cells. MGF helps these early cells grow up.

The new factor might make a good fertilizer for bone marrow, the body's seedbed of early cells. Concern for the marrow and for the immature but extremely important immune cells it contains often prevents physicians treating cancer from giving as much radiation or chemotherapy as they would like. An alternative, albeit a risky one, is to transplant healthy marrow to replace that destroyed by treatment. At present, only 3,000 to 5,000 bone marrow transplants are done a year in the U.S.

***GROWTH FACTORS** are made in mammalian cell-culture tanks at Genetics Institute, Inc.*

The practice stands to become more common if growth factors help marrow recover from the ordeal. With this in mind, Blue Cross and Blue Shield have already agreed to fund studies of GM-CSF as supplementary therapy for breast cancer patients. Scientists believe that *steel* factor could accelerate recovery of even more cell types.

The protein does more than promote blood cell growth, points out Peter Besmer, head of the Sloan-Kettering research team. It is also involved in pigmentation, because it stimulates melanocytes, and in embryogenesis, because it acts on germ cells. The multiple functions of *steel* factor have unraveled a biological mystery of 50 years' standing.

That is how long geneticists have recognized that two lines of laboratory mice, known as *steel* and *W* mutants, share the same defects—sterility, white or white-spotted coats and profound anemia caused by an inability to generate hematopoietic (blood-forming) cells. Only now have molecular biologists been able to track the cluster of flaws to a single protein. The growth factor, or ligand, signals a receptor on the surface of some stem cells, instructing them to grow and differentiate into blood, pigment or germ cells.

The animals' beautifully complementary defects made it obvious that one mouse had a defect in the growth factor receptor and the other had something wrong with the ligand itself. "We knew because of transplant studies done in the late 1960s and early 1970s that something was wrong in the *steel* mouse," Williams says.

When researchers put bone marrow from *steel* mice into *W* mice, Williams explains, the anemia of the *W* mice was cured, indicating that the hematopoietic cells in *steel* mice could function normally given the right environment. But doing the opposite, putting marrow from *W* mice into *steel* mice, doesn't cure the animal. The reason is that hematopoietic cells in *W* mice are intrinsically defective. "The receptor is broken, so they can't respond to growth factor," he notes.

This model is quite exciting to molecular biologists who study receptors. Now that scientists know what to seek, they are finding that receptor-ligand interactions are responsible for all kinds of cell growth, not to mention formation of bones and nerves. At least one dual receptor exists. It was found to bind both GM-CSF and IL-3. Immunex is developing a fused form of the two factors to treat patients with depressed counts of white cells and platelets.

Some researchers are concerned that stimulating cells increases the probability that cellular division will go haywire and cause cancer. "The genes that code for growth factors are the same damn genes that cause cancer when they lose their regulation," says Martin Rosenberg, vice president of biopharmaceutical research at SmithKline Beecham. To his mind, the risk of taking growth factors should be weighed cautiously against potential benefits. Use is probably justified to battle severe immunosuppression caused by chemotherapy, he concedes. Proponents of treatment with growth factors say that no one has acquired leukemia, even after long-term CSF administration.

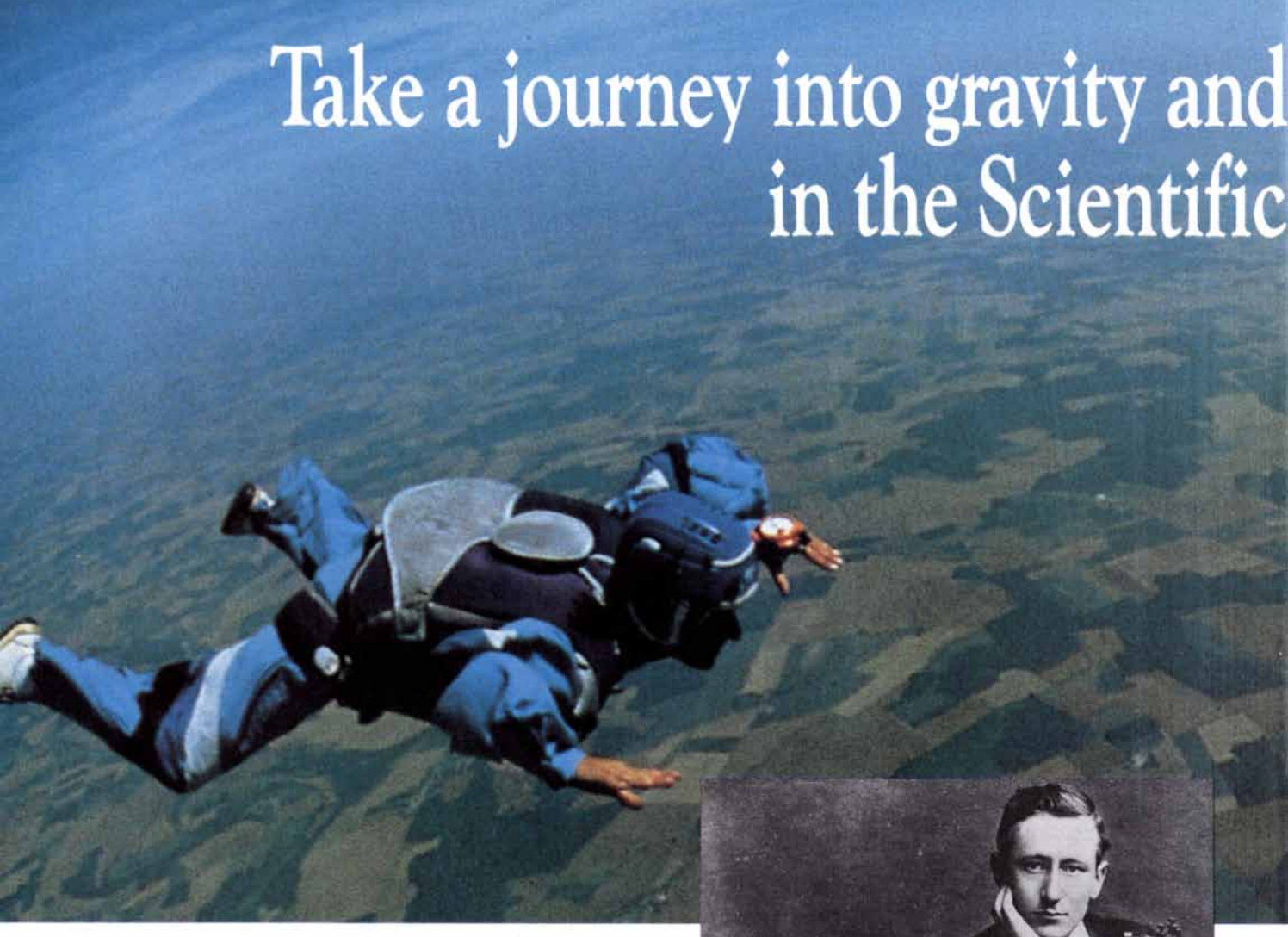
The apparent synergism of many growth factors may also make them tricky to use in humans. For now, companies are seeking FDA approval for single agents in specific indications. But so-called off-label prescriptions are likely as physicians experiment with giving multiple growth factors as "cocktails." Companies are already testing combinations of factors, even though they recognize that the FDA will expect to see each agent prove itself individually before giving approval for treatment with more than one factor. "I think that's going to change, as the FDA gets more familiar with these factors," asserts L. Patrick Gage, executive vice president of scientific affairs at Genetics Institute. "If they see cases where there's compelling clinical benefit from a combination and only marginal results from a single agent, they will adjust to that."

Blood cell growth factors will be useful for more than therapeutics, Williams asserts. "For those of us in the lab, they're also tools to enable us to understand how bodily systems work." In particular, *steel* factor could be a springboard to discovery of other cell-stimulating factors, because it helps to keep stem cells alive. The cells could then be used as a target for other factors. It doesn't necessarily follow that the first blood cell growth factors to be found will be the most useful, Gage notes. "We might find the most interesting one next week."—*Deborah Erickson*

THE PROMISE OF BLOOD CELL GROWTH FACTORS

EPO	Approved by the FDA in 1989 for treatment of anemia associated with chronic renal failure. Increases production of red blood cells. In testing for other anemias, including sickle cell. **Major developers:** Amgen, Genetics Institute, Genzyme, Hoechst, California Biotechnology
GM-CSF	Approval expected in early 1991 for bone marrow transplant failure. Stimulates growth of white blood cells, particularly granulocytes, macrophages and monocytes that fight infection and regulate other immune system cells. **Major developers:** Immunex, Genetics Institute
G-CSF	Approval anticipated in early 1991 for white blood cell suppression caused by chemotherapy. Increases production of granulocytes, which are involved in inflammation and defend against bacteria and parasites. **Major developers:** Amgen, Chugai, Kirin
M-CSF	In clinical trials to bolster the immune system during cancer treatment. Controls production of macrophages and monocytes. **Major developers:** Genetics Institute, Cetus
IL-3	In early human trials to treat white blood cell and platelet deficiencies. Stimulates growth and differentiation of many cell types and so may prove most useful in combination with other factors. Also called multi-CSF. **Major developers:** Immunex, Genetics Institute, Gist-Brocades
PIXY-321	Expected to begin human testing in 1991. As fused form of GM-CSF and IL-3 that fits a dual receptor on bone marrow cells and stimulates both platelet and white blood cell production. Considered a second-generation CSF. **Developer:** Immunex
***Steel* factor**	First reported in October 1990. Influences production of a wide variety of blood cell types at an early stage of their development. **Developers:** Amgen, Immunex, Sloan-Kettering/Roche

Take a journey into gravity and in the Scientific



From Signals, *Guglielmo Marconi in 1896. Courtesy Marconi Company Ltd.*

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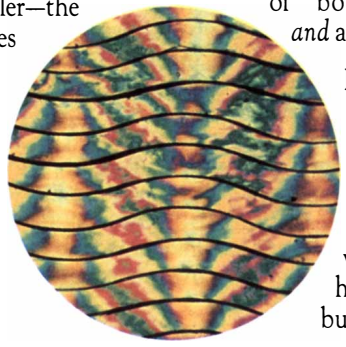

From The Science of Structures and Materials, *a polarized light view of a stressed graphite fiber-epoxy resin composite. Courtesy Tsu-Wei Chou.*

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Changing Mission

Can the national laboratories tackle the trade wars?

Located from Albuquerque to Long Island, the Department of Energy's nine huge laboratories provide 48,500 jobs, some 29,000 of them held by engineers, scientists and technicians. Known collectively as the national laboratories, they command a nearly $6-billion annual budget, the largest part of which is devoted to defense work. But as the cold war wanes and Congress reins in military spending, justifying such hefty spending may prove more difficult than it has in the past.

That was almost certainly on the mind of Secretary of Energy James D. Watkins last November when he organized a blue-ribbon panel to report on the future of all the DOE laboratories, which include many smaller facilities. Watkins, who has called the laboratories a "jewel in the national intellectual crown," has directed his panel to develop a "strategic vision" that will guide the laboratories into the next century. In doing so, however, Watkins set no precedent. One of the group's first activities was to review 10 reports that have been done since 1962, on both the DOE laboratories and the federal laboratory system as a whole.

As in the past, a sweeping restructuring of the DOE laboratories is unlikely. Neither the Bush administration, notoriously averse to anything that suggests government-directed industrial policy, nor Congress has proposed a wholesale redirection of the laboratories' mission—say, to meet an emerging national need such as bolstering U.S. industrial competitiveness. And legislators are loathe to close down a laboratory. "It's kind of like closing a military base, and obviously you're not going to get much support for that from Congress," says Joseph P. Allen, director of the Department of Commerce's office of technology commercialization.

In the absence of radical cuts in staff and operations, Watkins and his allies invoke the slogan of "technology transfer" to show the laboratories' value in peacetime. The DOE has mapped out an evolutionary strategy that foresees using technology for what one laboratory director has called the "four Es": energy, environment, economy and education.

Like the recent study, that direction is nothing new. The laboratories point proudly to specific attempts at industry outreach that date back to their earliest years. They contributed significantly, for example, to the development of radioisotopes for nuclear medicine beginning in the 1940s. But their efforts have fallen short of expectations, and they have been under pressure over the past decade to do better.

The Stevenson-Wydler Technology Innovation Act of 1980 elevated technology transfer—everything from cooperative research to informal visits from colleagues in industry—to the level of a policy goal for all federal laboratories. But the 1980 law failed to clear away red tape and legal barriers to moving technology from laboratory to industry. So Congress has spent the past 10 years pushing through new laws and amendments to the original law.

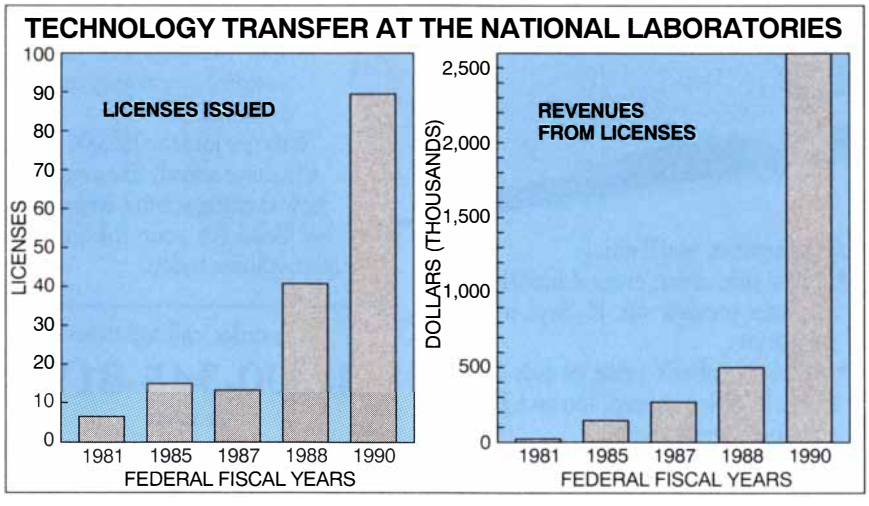
By many accounts, updated legislation was needed because DOE headquarters in Washington, D.C., had been dragging its feet. The National Competitiveness Technology Transfer Act of 1989 was supposed to put a fire under the agency by streamlining the process of getting laboratories to work with the private sector. The DOE says it has begun to respond, but laboratory insiders say that the bureaucracy, averse to risk, has used the law to find ways to "micromanage" technology-transfer programs in the various laboratories. It took more than a year for many of the laboratories to hammer out with headquarters the technicalities of how to enter cooperative partnerships with industry. "There's no doubt that bureaucratic obstacles have been raised," says Senator Jeff Bingaman from New Mexico, who sponsored the 1989 law.

Slowness to change may also stem from what is colloquially known as the "culture problem." Even though some of the laboratories are actually run by a private corporate contractor, such as Martin Marietta or AT&T, there has been a strong sense among laboratory scientists and engineers of being part of an elite technocratic cadre, whose mentors were the original Manhattan Project team.

The laboratories, their directors argue, are among the few places where long-term research can be pursued, unhindered by the type of corporate takeover attempts that led to the gutting or outright disappearance of some big private laboratories during the 1980s. "When it comes time to make a draconian financial decision in the paneled boardrooms, quite frequently the R&D labs are the first place to get hit in the neck," says Alvin W. Trivelpiece, director of Oak Ridge National Laboratory.

Detachment from the pressures of the marketplace, however, may also lead to detachment from the needs of the marketplace. In fact, university researchers, who depend on private companies for some of their funding, may make more suitable partners for industry. "Our overall experience has been that scientific collaborations with the national laboratories, researcher to researcher, have been less successful than those at the university level," says Frank B. Sprow, Exxon's vice president of corporate research.

The upshot is that technology transfer still makes up a relatively small per-



INDUSTRIAL COLLABORATION is part of a superconductivity research program at Oak Ridge National Laboratory.

centage of laboratory activities—and it sometimes serves only to underscore differences between the research and development environment in the laboratories and in industry. Some collaborative efforts have succeeded. Perhaps the most interest has been generated by pilot centers at Oak Ridge, Los Alamos and Argonne laboratories for research into high-temperature superconductivity. In others, however, the relationship has been an uneasy one.

The "steel initiative"—an attempt by Congress to enlist the national laboratories, among others, to help domestic steelmakers find "leapfrog technologies" to surpass the Japanese and Germans—has achieved only halting progress in bringing laboratory researchers and industry together. In fact, the laboratories were left out when the American Iron and Steel Institute drew up plans for the program's most ambitious project to date—one that would reduce steelmaking to a single-step process.

The national laboratories are just beginning to catch up with such institutions as the Massachusetts Institute of Technology and Stanford University in licensing their technology. In the 1990 federal fiscal year, which ended September 30, the laboratories issued 89 licenses for patents and software, bringing in a total of $2.6 million. That is a large increase from a decade earlier, when almost no licenses were issued. But M.I.T.'s 60 to 80 annual licensing agreements have produced $3 million to $4 million in revenues during each of its last three fiscal years. And most of the M.I.T. licenses came out of a research budget of just over $300 million.

Bingaman, for one, wants the laboratories to step up their efforts. And he suggests they heed an upcoming report on 30 critical civilian and defense technologies due out in February from the White House's Office of Science and Technology Policy. "I hope that a growing part of the labs' mission in the coming years will be to maintain U.S. leadership in some of the areas pointed out by this report," Bingaman says.

Without a hard shove from outside the laboratory gates, the technical masters of the Manhattan Project and Star Wars are unlikely to discard 45-year-old drawing boards. "Each national laboratory has an industrial affiliation program, but these efforts are very much Band-Aid solutions to the problem of technology transfer," says Robert C. Dynes, director of physics research at AT&T Bell Laboratories. "What they need to do now is to construct whole organizations for delivering the products of research and development to industry." —*Gary Stix*

An acoustic sensor spies on insects

Shhhhh. Did you hear that? Crunch, munch, slurp... It's the sound of insects and their larvae eating the heart out of apples, burrowing through mango flesh, corrupting apricots. All manner of fruits—as well as grains, nuts and woods—are feasting places for insects. The tab is paid by growers, millers and importers and exporters the world over.

At present, the only way of detecting infestation in harvested commodities is to examine visually random samples. Inspectors from the U.S. Department of Agriculture (USDA) select one fruit from each crate brought to federal point-of-entry stations and cut it open to look for larvae. The slice-and-seek technique is far from infallible and is time-consuming as well. Plenty of produce is wasted simply in proving the lot is sound. Inspectors also sift grain in search of adult insects, but there's no telling what's inside a kernel of wheat from looking at it.

Listening might be more effective. Scientists have mused about eavesdropping on feeding insects since at least the 1920s. But it was not until 1982 that J. C. Webb, now a retired USDA engineer in Gainesville, Fla., proved it could be done on a practical basis. Webb first detected the vibrations of insects biting and moving around in kernels of wheat and centers of grapefruit under laboratory conditions with thousands of dollars' worth of equipment.

The technology could soon be ready to move from laboratory to market via a recently developed listening device that will cost only a few dollars to manufacture. "We've designed a new acoustic sensor more appropriate to the task," declares Webb's collaborator, Robert Hickling, an engineer at the University of Mississippi's National Center for Physical Acoustics. Neither he nor Webb will describe the system in detail until patent applications have been filed. Hickling will say that the sensor concentrates on a band of low frequencies between 800 and 900 hertz, because higher ones are attenuated in the fibers of fruit and grain. A computer then reviews the readings within 10 to 15 seconds to determine whether pests are present.

Lots of people are interested in a practical acoustic sensor for insect detection. "The grain industry is demanding some sort of technology to find out what's happening in storage," says Richard Backus, associate deputy administrator of plant protection and quarantine at the USDA. A tenth of the grain stored in the U.S. is lost each year; other parts of the world commonly lose 20 to 50 percent or more of their cache.

International interest in such a device could be considerable. Almost every country is plagued with a pest that can wreak devastation if introduced to a similar climate. Japan, for instance, which buys more than $100 million of fresh grapefruit from Florida each year, does not have the Caribbean fruit fly found in the Sunshine State and does not intend to. It imposes strict quarantine laws, as do other nations hoping to avoid the dread Mediterranean fruit fly, the Queensland fruit fly from Australia, the Malaysian fruit fly and scads of others. "This could work out," says Roy McDonald, research leader at the Agricultural Research Service in Orlando, Fla. "No one wants anyone else's fruit flies." —*Deborah Erickson*

Hole or Doughnut

Will E-beams become competitive in high-density chip making?

Semiconductor manufacturers have begun to think about the lithographic techniques needed for a coming generation of memory chips that can store 256 megabits or even a gigabit of information. Patterning transistors and other tiny features of these chips will stretch photolithography, the mainstay of chip making, to the limit.

Reports of a coming demise of photolithography have always proved premature. But this time chip producers who will wrestle with how to etch tenth-of-a-micron-wide circuits on silicon wafers may have to consider other forms of radiation. Two of the leading techniques now being studied are electron-beam lithography and X-ray lithography.

Conceptually, electron-beam lithography appears to lose out to X rays. Current X-ray lithographic and photolithographic techniques employ masks through which an image of the entire chip's circuitry is projected onto a silicon wafer. That makes the process about 50 times faster than electron-beam lithography, because E-beams must be guided through the tediously slow process of writing a circuit pattern on the wafer line by line. The process, called direct write, is still widely used for patterning circuits onto masks and making specialized chips.

AT&T Bell Laboratories may have come up with a mask for E-beams that may help make the technique every bit as fast as X-ray lithography. Researchers there have succeeded in dealing with one of the major disadvantages of using electrons to project a circuit image through a mask—namely, the "doughnut problem."

Early attempts to make E-beam masks relied on very thick stencils of silicon, thick enough to block out the background so that only circuit lines would be exposed. But chip makers who wanted to create a mask to protect an enclosed area from exposure—equivalent to the hole in a doughnut—had no easy way to affix the hole to the rest of the mask. Although circuit designers may never have an occasion to print a doughnut, the problem of mapping out enclosed spaces is a familiar one.

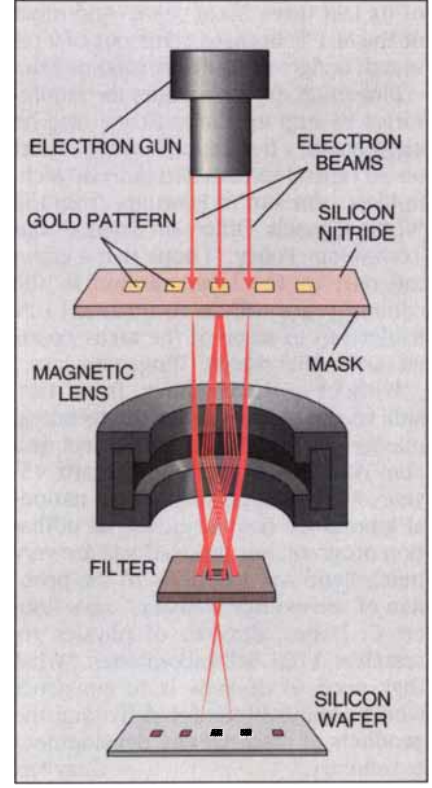
Doughnuts are not a problem in X-ray lithography and photolithography, because the opaque section of the mask is a thin metal pattern that sits atop a transmissive substrate—glass or quartz for photolithography; silicon for X rays. The doughnut hole simply rests on the substrate. The metal then absorbs photons of light or X rays, and the radiation passes through the transparent part of the mask to expose the wafer.

That approach does not work with E-beams, because their high energy would penetrate the thin metal on a conventional mask. To absorb the electrons, the metal areas of the mask might have to reach 25 microns in thickness while resting on a transmissive silicon substrate of no more than a micron: in effect, a house on a dangerously thin sheet of ice.

The Bell Labs mask gets around these problems by being entirely transparent to electrons. Devised by physicists Steven D. Berger and J. Murray Gibson, the mask consists of a half-micron-thick film of silicon nitride through which electrons stream. The circuit pattern on the mask is created with gold, tungsten or another material with a higher atomic number than silicon. The metallic areas do not block the electrons. Instead their greater negative charge scatters the electrons from the beam at sharp angles.

Most of the deflected electrons can then be absorbed using a very thick metal filter. Meanwhile the rest of the electrons move straight through the sil-

PROJECTION ELECTRON-BEAM LITHOGRAPHY



icon nitride areas of the mask and pass unimpeded through a hole in the middle of the filter. The aperture of the filter can be widened or narrowed, like the f-stop of a camera, to control the contrast of the image. The system also contains several magnets that act as lenses to reduce by four or five times the image etched on the mask.

The Bell Labs team members reported in last July's issue of *Applied Physics Letters* that they had printed a simple grating pattern in an area of 50 square microns. Then, at the Materials Research Society conference in November, they told how they had etched a pattern that is a millimeter square.

Although those results are impressive, the largest area printed is still at least 100 times smaller than would be required for actual chip production. Berger and Gibson's competitors across the Hudson River at the IBM Thomas J. Watson Research Center are skeptical of how far the technology can be taken. An array of technical problems lies ahead for the AT&T researchers, asserts Dieter Kern, manager of nanostructures and exploratory devices there. This is one reason that IBM dropped its experiments with E-beams in the 1970s and later went on to concentrate on X-ray lithography.

Finding a way to work with a thin-film mask measuring 2,500 millimeters square and no more than a micron thick may prove daunting. "What if it expands by a fraction of a micron? That's all it takes for it to become nonfunctional," Kern points out. Other technical issues may prove even more intractable than the mask. "It will be difficult to design, build and operate lenses for a 100-millimeter-square chip with negligible distortions," Kern says.

Even though high-density chip manufacture is one obvious use for the mask, AT&T is not saying exactly how it will use the technology. Kern believes the method may prove itself in making the tiny gratings used for tuning light frequencies in semiconductor lasers.

But the possibility that AT&T's mask could expose an entire chip holds the broader promise of producing a breakthrough. "Everything Kern says is an issue," Berger comments. "But the driving force is what we would get if we succeeded. What we've done is to put the technology back on the table as something to consider."

If they do succeed, projection electron-beam lithography machines—cheaper than the synchrotrons used to produce X rays—may become a contender in the race toward gigabit chips that can store a book 35 times the length of *War and Peace.* —*Gary Stix*

Reach Out

Touch is added to virtual reality simulations

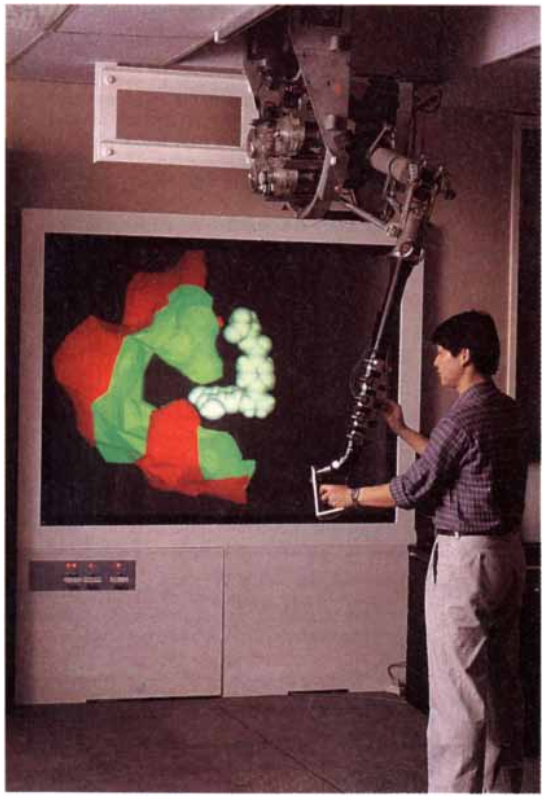
Vivian Cody, a crystallographer at the Medical Foundation in Buffalo, N.Y., thought she understood how anticancer drugs and enzymes managed to bind together. But when she began to manipulate a pendulous mechanical arm to move a simulated drug molecule into active contact with an enzyme, sudden resistance from the device she was holding told her she had failed. "I wanted to see how I would be at this video game for docking a molecule," Cody says. "When I pushed the drug into a pocket in the enzyme, it felt like I had driven into a brick wall."

Cody was among the first to try out a new twist in using computers to create the simulated experiences known as virtual reality. Dubbed force feedback, the technique allowed Cody to "grasp" what she was seeing on the computer screen. The servodevice she was holding literally pushed back. It pulled and twisted, too—sometimes quite hard. The motions simulated the magnitude of attraction, repulsion and torque that occurred as the sum of atomic interactions between the two molecules.

Force feedback adds feeling to the sight and sound of virtual reality. Cody used the system at the University of North Carolina at Chapel Hill, a major center for such research. There Frederick P. Brooks, Jr., a professor of computer science, began to work on force feedback in the early 1970s as part of what he called Project GROPE.

Brooks's most recent exercise in force feedback allows a chemist to control a servo to move the drug around the display until it binds with the enzyme at the lowest and most stable energy state. The servomanipulator, a hand-me-down from Argonne National Laboratory that once controlled a robot arm for handling radioactive materials, works like the joystick in a video game.

The display shows the relative positions of the drug and the enzyme, and "energy thermometers" show the level of binding energy. The software that controls the servo represents both force and torque in three dimensions with a standard force model for molecular interaction devised by Peter A. Kollman of the University of California at San Francisco.



***FORCE FEEDBACK** is used at the University of North Carolina at Chapel Hill to help a researcher understand how a drug* **(white molecule)** *binds with an enzyme. Photo: Bo Strain.*

The technique is proving to be far more than an amusing game for chemists. Sensing the size and the direction of forces allows them to work more efficiently. "It gave me an intuitive feel of where I wanted to go that I couldn't get from looking at numbers," Cody says. A study by Ming Ouh-Young, a former colleague of Brooks now working at AT&T Bell Laboratories, showed that a group of biochemists could find the correct way to dock the drug within the enzyme almost twice as fast if they were using force feedback.

Feeling the effects of applied forces may prove its worth in other areas. The technique may become a powerful teaching aid. First-year physics students at the University of North Carolina used a force-feedback system to examine the electromagnetic forces within a vacuum tube. Using the system helped to dispel the idea that the field was greater at the plate than at the cathode.

A still more sophisticated step is to model the very texture of objects. At the Massachusetts Institute of Technology's Media Laboratory, Margaret Minsky and her co-workers have devised Sandpaper, a force-feedback system that tests whether someone can arrange several grades of sandpaper by roughness. Roughness is simulated by moving a joystick over a series of tiny imaginary "bumps." The sensation is somewhat akin to moving a pencil over a rough surface. When moving "up" a bump, the system computes a force proportional to the slope of the bump.

Texture perception may not be limited to the crude feel of sandpaper. Minsky wants to simulate soft and sticky substances as well. If she does, a housebound child may one day be able to communicate to a parent at work exactly how gooey the kitchen floor feels after spilling a jar of honey.

That's because AT&T wants to use force feedback to augment voice in telecommunications. To do so, it is experimenting with games to learn how to let callers reach out and touch someone or something. One game requires the player to move through an invisible maze using a joystick that refuses to budge on hitting a maze wall.

Researchers at Bell Labs are already considering other possibilities. In a project still in planning, a tactile glove might apply pressure on the palm of the hand. It might enable an attending physician to sense and correct the movement of a student's scalpel during surgical practice on a cadaver.

Force feedback may also end up as a tool for designing easier-to-handle consumer products. At the Institute of Engineering Mechanics at Japan's University of Tsukuba, investigators have reported on a virtual reality system for judging the "feel" of a prototype camera displayed by computer-aided design software.

While lab experts dream on, perhaps the most successful practical example of force feedback, besides flight simulators, is an Atari video game called Hard Drivin', which transmits the physical forces on a race car through the steering wheel—conveying the sense of bumpiness when the driver veers from the road. In fact, Brooks thinks the mass market for ever more sophisticated video games may take the lead in creating servodevices to convey force. He hopes that equipment will then get passed on to university researchers. *—Gary Stix*

THE ANALYTICAL ECONOMIST

Don't write off Marx

You might think the collapse of centrally planned economies all across Eastern Europe would pose a problem for Marxist economists. On the contrary, the recent revolutions "have removed a millstone from the neck of leftist economists in the West," says Samuel S. Bowles of the University of Massachusetts at Amherst. Bowles says he no longer has to explain to onlookers that Stalinist economics has even less to do with Marxist-style socialism than Sweden does with the classic laissez-faire capitalism of Adam Smith.

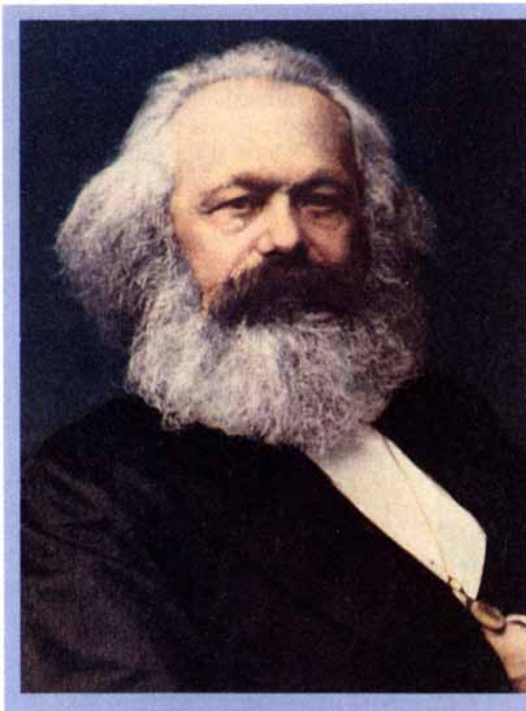
Indeed, he and his fellow members of URPE (the Union for Radical Political Economics) are now free to insist that many of the recent economic ills in the West vindicate Marx's ideas. And they predict that newly independent Eastern European economies won't succeed without a strong dose of "market socialism"—markets tempered by public decision making and perhaps public ownership of enterprises.

To proponents, the vitality of Marxist theorizing continues unabated. Marxism, says Stephen A. Marglin of Harvard University, has an advantage over mainstream economics: it just tries to explain how capitalism works. The mainstream approach must fit reverse repossession-agreement bond trading into the same framework as commerce among the Trobriand islanders or reciprocal gifts among the Kalahari !Kung. The casualties of generalization include a viable theory of the role of individual banks, a realistic concept of uncertainty and any understanding of behavior not based on economic optimization.

Marxist business-cycle theories explain periods of economic expansion and contraction better than do mainstream ones, for example, contends Duncan K. Foley at Barnard College of Columbia University. The mainstream theories, he explains, are handicapped by the assumption that capitalist economies are inherently stable.

Ironically, Marxist economists think the events of the past decade furnish the best evidence that they were right all along. Capitalist countries in the late 1970s appeared to be doing fairly well at meeting the needs of all their citizens, Bowles says. But the 1980s saw capitalism unchained in the U.S. and elsewhere, leading to increasing inequality, public disaffection and the unraveling of the social fabric—not to mention hundreds of billions in unpaid bills. "If anything, the task of social control over investment decisions is more pressing than ever before," he contends.

Furthermore, Marxists say they have pioneered studies of many issues that are now of increasing interest to mainstream economists. One, Foley says, is the social organization of workplaces and another the methods by which firms extract effort from employees.



"Ninety-nine percent of what Marx wrote was [about] capitalism. Only a tiny part was proposals for a socialist alternative."
Duncan K. Foley

Of course, Foley notes, Marxism has its glaring failures as well. Perhaps the most obvious is the concept of "immiserization"—the idea that the oppressed working class under capitalism would necessarily grow poorer and poorer until it finally threw off its chains. Faced with the economic advances of the late 19th century, Marx abandoned absolute immiserization for a relative version in which the gap between capitalists and proletarians would widen, although workers' absolute living standards might improve. But even that supposed trend has been difficult to discern throughout the capitalist world.

What, then, does Marxism have to say about the nations of Eastern Europe in their transition from central planning and state ownership to some as yet undetermined economic form? Not much. Left-leaning economists were "caught flat-footed" by the sudden collapse of totalitarian socialism, Foley says. They have played a relatively minor role in the restructuring now under way.

Marglin thinks radical political economists in the West have a great deal to offer the Easterners but is not optimistic that they'll take it. "I can understand perfectly that people in Poland want nothing to do with anything that has the name 'Marx' associated with it," he says. Conservatives have been quick to fill the vacuum, as have others whom Foley chides for having "hardly any politics at all."

If Eastern Europe does pursue a whole-hearted free market path, Bowles says, the results are not likely to be the visible prosperity of Reaganite America or Thatcherite Britain. The sad current state of the region's economies augurs more for the inflation-poverty cycle of, say, Bolivia or Paraguay. "With very few exceptions, nations don't have economic development under laissez-faire capitalism," he asserts. Government involvement in the economy was crucial for France, Sweden, Germany and even the U.S. and England earlier in their histories.

So Foley predicts that eventually the Eastern economies will have to come at least part of the way from laissez-faire capitalism toward socialism. "It's very difficult to maintain political stability without some kind of safety net," he says, and social welfare traditions in the region are fairly strong. (Indeed, the noted liberal Bismarck established some of the first such programs.)

Bowles takes a stronger view: "Eastern Europe is closer to true socialism today than it has been in recent memory." That isn't very close, he admits. At best, he and his colleagues hope that the countries of the region work out a middle path between private property and centralized state control.

In the interim, says Thomas E. Weisskopf of the University of Michigan at Ann Arbor, the quest for solutions "may lead to real experiments"—economic gambles on a vast scale. That is one point, apparently, on which both the radicals and conservatives agree.

—Paul Wallich and Elizabeth Corcoran

MATHEMATICAL RECREATIONS

The true story of how Theseus found his way out of the labyrinth

by Ian Stewart

Theseus had made only five turns through the labyrinth when he came to the end of his rope. "Drat. Why didn't Ariadne give me a longer string?" he muttered. Petulantly, he flung the spool to the floor. Dare he go back and face the derision of King Minos and the citizens of Crete?

Heroes never turn back, he thought. He unsheathed his sword and strode ahead boldly, all senses alert for the first sign of the terrible Minotaur. Catching a whiff of a rather bovine sort of smell, Theseus knew he was headed in the right direction. Farther into the labyrinth he followed the scent. He tried to keep track of where he was, but all the tunnels looked the same. He soon realized he was desperately lost.

Passing one corridor, he heard a gurgling snort. He moved toward the sound, straight into a soft wall, a warm wall, a moving wall! Holy Zeus, it was the Minotaur!

Theseus swung his sword valiantly but ineptly. He missed the beast and hit a stone wall with such a mighty blow that the sword fell from his hand.

"Put that silly pigsticker away before you really hurt yourself!" roared the Minotaur.

"I will not yield, you son of a bull! I, Theseus, will avenge the deaths of all the maidens and youths that you have devoured."

"I never ate anybody. Don't you know bulls are vegetarians? All those maidens and youths are still wandering around the labyrinth. They can't find their way out either."

Indeed, this Minotaur looked nothing like a bloodthirsty bull. He resembled a Guernsey cow with horns. "Why don't you just settle down, Theseus? You're going to be stuck in this maze for a long time. Maybe you can help me solve a puzzle."

"The only puzzle that interests me is how to get out of this labyrinth," Theseus retorted.

"Well, had you been smart enough to bring a map of the labyrinth," the Minotaur said, "we could solve the maze by blocking off all the dead ends."

"And where do you suppose I could have found such a map?" snapped Theseus indignantly. "After Daedalus built this place, do you think he filed a copy of the blueprints with the Cretan County Council? No, he destroyed all the plans. Any other bright ideas?"

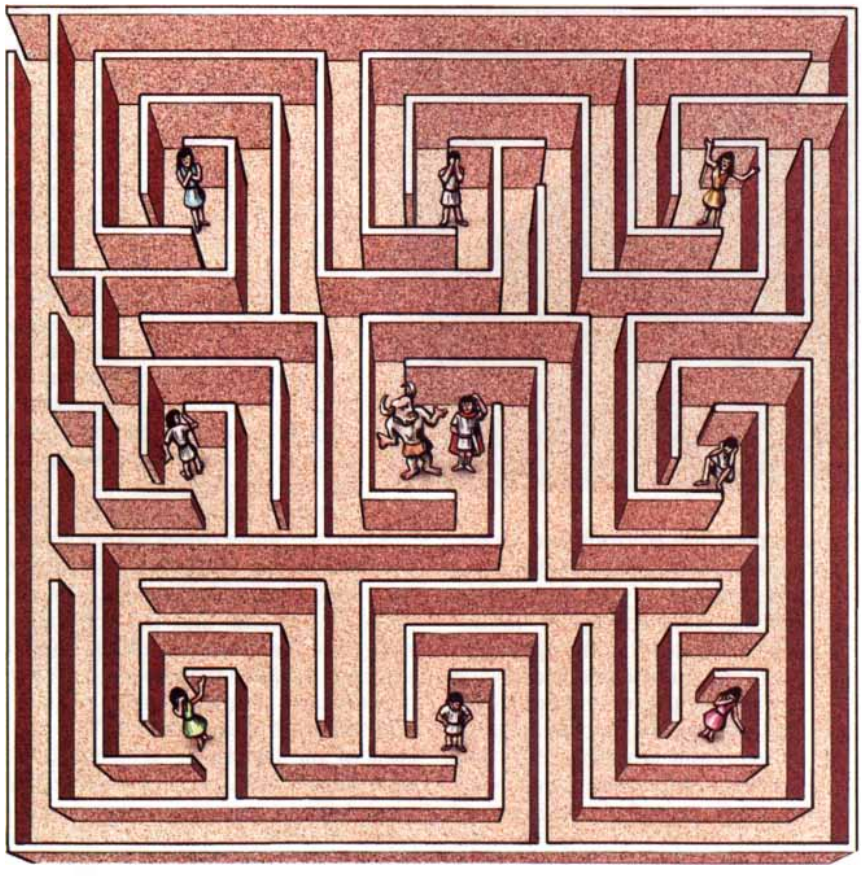
"Well, we could try the old left-hoof-on-the-wall trick," said the Minotaur.

"What's that?" asked Theseus, perking up.

"When you first enter the labyrinth—or any maze, for that matter—you put your left hoof, or hand, on the wall, and keep it there. That trail guarantees that eventually you'll find your way out again."

"Thanks for the tip," replied Theseus gratefully. Putting his left hand against the wall, he raced off through the labyrinth to find the way out.

Three days later, an exhausted Theseus limped into view. "I knew you would be back," admitted the Minotaur. "I've tried the left-hoof-on-the-wall method a dozen times. As I warned you, the method is guaranteed to work only if you use it from the very beginning. If you start to use it from somewhere inside the maze, you can only be sure that you'll return to your starting point. All that happens is you traverse one complete connected system of walls, and if that system isn't connected to the entrance, well, it gets you absolutely nowhere."



Can Theseus and the Minotaur find all the maidens and youths without walking through any hallway or junction more than once?

"You might have told me all that three days ago!"

"Didn't want to discourage you. But truly I don't think we will ever get out of this maze. You see, if you and I and all the others trapped in here were to escape, it would create quite a scandal. King Minos would have to explain to the citizens of Crete why he imprisoned all of us. Do you think he would let that reporter chap, Homer, write about us in the tabloids? Oh no. Minos, like any good politician, would do everything in his power to cover up the story. As soon as we did escape, he might decide to really sacrifice us to the gods."

"I would much rather fight King Minos than languish in this maze for eternity," the hero proclaimed boldly. "There must be a way out of this mess."

"While you're planning our great escape, Theseus, maybe you have time to solve a riddle I've just invented. A eunuch, a nymph, a cyclops and a satyr are trying to cross the river Styx. They find a boat that holds two of them at most. Only the eunuch can row the boat. If the cyclops is left on shore with the nymph, he'll eat her. If the satyr is left alone with the nymph, he will... um, well, let's not go into it. How can the eunuch get all four safely across?"

"Don't bother me about that now," Theseus complained. "Don't you know anything else about mazes?"

The Minotaur scratched a horn with one hoof. "Well, the most important thing about a maze is how the junctions connect. The lengths of the tunnels don't matter."

"I'm not sure I can agree with that," said Theseus, nursing the blisters on his feet.

"Well, the lengths of the tunnels don't affect the path you take to get out. Right? So we're talking about the topological properties of the maze, not the metric ones. Now, we can represent the topological essentials by a graph. Nodes in the graph correspond to junctions in the maze. Edges in the graph represent tunnels. Then the problem of getting out of a maze—or finding a particular place within it—becomes a problem of traversing a graph from one node to another. A key theorem in graph theory allows one to transform a maze problem into a graph problem."

"Terrific!" Theseus exclaimed. "Now we're getting somewhere. I adore theorems. Pythagoras once showed me a real stunner, something about a hippopotamus of a bright triathlete."

"Not now, Theseus. Let's concentrate on the maze theorem. Two nodes can be joined by a continuous path if and only if they lie in the same connected component of the graph."

"Hmm," Theseus murmured doubtfully. "What's a connected component?"

"It is the set of all nodes that can be reached from a given one by a continuous path," the Minotaur recited proudly.

"Ah! Let me see if I've got this right. What you're saying is that two nodes can be joined by a continuous path if and only if there exists a continuous path that joins them?"

The Minotaur was deeply offended. "Well, you could put it like that, but it seems to me you're trivializing an important concept."

"That may be so. But I think we need something a little more constructive."

"Oh, all right. You want a maze-threading algorithm."

"An amazing what? Do you mean the infamous Algorithmos Labyrinthou, the nine-headed monster with razor-sharp fangs and snakelike hair?"

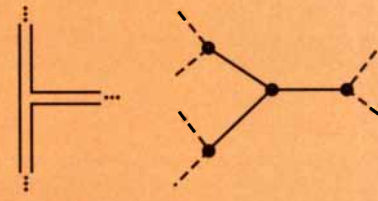
"No, Theseus, an algorithm is not a beast. It's just a word that is going to be derived from the name of a ninth-century mathematician, Muhammad ibn Musa abu Abdallah al-Khorezmi al-Madjusi al-Qutrubilli. The name 'Al-Khorezmi' became 'al-Gorizmi,' then 'algorism' and finally 'algorithm.' The word is used to describe a specific procedure such as a computer program."

"What's a computer program?"

"Never you mind. In 1892 M. Trémaux is going to invent a maze-threading algorithm. Nearly a century later the algorithm will be rediscovered by John Hopcroft and Robert Tarjan in the context of graph theory, which, as I've said, is really quite similar to maze theory. The maze-threading algorithm is called depth-first search [*see box below*]. The depth-first search algorithm is especially appropriate for solving mazes, because it is possible to apply it without having a map. It involves only following local rules at nodes and keeping a record of nodes and edges already traversed. Even if you're

DEPTH-FIRST SEARCH AND MAZES

The depth-first search algorithm can solve any maze, providing that a record is kept of each turn. The idea behind the algorithm is to give top priority to pushing deeper into the maze. To simplify the application of the algorithm, a maze must first be converted into a graph composed of triple junctions, as shown at the right.

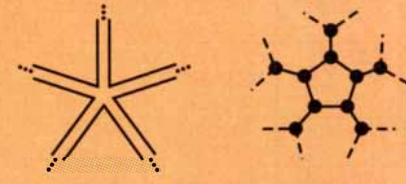


Transforming a junction into a graph

The depth-first search algorithm visits all nodes in the same connected component as the starting node. In particular, it can be terminated when it hits a "finishing" node, the maze's exit. The algorithm begins as follows:

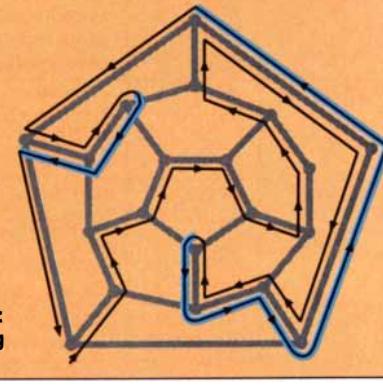
1. Begin at any chosen node.
2. Visit any adjacent node that has not yet been visited.
3. Repeat step 2 as far as possible.
4. If all adjacent nodes have been visited already, backtrack through the sequence of nodes that have been visited until you find a node that is adjacent to an unvisited node and then visit that one.
5. Delete any edge that has been backtracked.
6. Repeat steps 2 through 5 until you return to the starting node and there are no unvisited nodes adjacent to it.

Eliminating dead ends and turns



Replacing a multiple junction with triple junctions

The algorithm moves to all nodes in the connected component of the graph that contains the starting node. The algorithm is quite efficient: the number of steps is at most twice the number of edges in the graph.



Depth-first search of a graph: blue lines show backtracking

trapped in the maze, the algorithm can help you find the way out."

"Brilliant!" shouted Theseus. "This idea will secure our freedom! All we have to do is carry out a depth-first search of the labyrinth!"

But the Minotaur seemed unimpressed. Then he added, "Trouble is, Theseus, you need some way to mark each junction so that you know you've been there before and where you came from. Did Ariadne happen to include a stick of chalk in your lunch pack?"

Theseus lamented that chalk was unaccountably omitted from his equipment. "I've got a sword, though. I'll scratch the walls."

"No chance, these rocks are as hard as diamond."

"Blast."

They sat in silence, each lost deep in thought. Finally, the Minotaur sat bolt upright. "Hey, I've just had an idea."

"Bully for you," sneered Theseus. "Does it get us out?"

"No, it's an idea about the eunuch's puzzle."

"Oh, that," said Theseus derisively.

"You see, I've just realized that my puzzle—and many like it—are really maze-threading problems in disguise."

"You mean the boat to the underworld must go through a maze?" asked Theseus. "That'll be news to Charon."

"No, not a maze of tunnels and junctions—a logical maze."

"Minotaur, I have no idea what you're talking about."

The Minotaur tried to explain. Each possible position in the eunuch's puzzle can be thought of as a node in a graph, and each move from one position to another can be considered an edge that joins the corresponding nodes. The Minotaur's idea was to use the depth-first search algorithm to traverse the graph. Then, by eliminating any backtracking, one would have a solution to the puzzle [*see box below*].

"I guess you've invented the MUPS algorithm, the Minotaur's Universal Puz-

DEPTH-FIRST SEARCH AND PUZZLES

Depth-first search is a powerful method for solving puzzles in which various rules govern the movement of people, animals or objects from a given position to a selected finishing position. Depth-first search will work, however, only if the number of possible positions is finite. The algorithm takes the following form:

1. Whenever you first come to a new position (including the initial position at the start of the puzzle), list all possible positions that can be reached from it.

2. From the starting position, choose at random and then make any move that leads to a "new" position (one that has not yet occurred).

3. Repeat steps 1 and 2 as far as possible.

4. If all possible moves lead to "old" positions, backtrack through the sequence of moves that have been made until you find a position from which it is possible to move to a "new" position. Then make that move.

5. Henceforth ignore any move that has been backtracked.

6. Repeat steps 1 through 5 until you reach either the desired position or the starting position, having exhausted all possibilities. In the latter case, the puzzle is unsolvable.

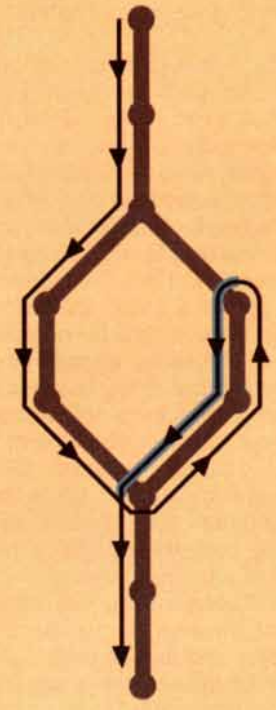
One can apply depth-first search to the eunuch's puzzle. A eunuch, a nymph, a cyclops and a satyr must cross the river Styx in a boat. Only the eunuch can row, and the boat has room for only one other. Neither the satyr nor the cyclops can be left alone with the nymph.

The participants can be represented by E (eunuch), C (cyclops), N (nymph), S (satyr). The symbol || ("sticks") indicates the river Styx. For example, the code [EN || CS] means that the eunuch and the nymph are on the left bank and the cyclops and the satyr are on the right. The depth-first search algorithm solves the eunuch's puzzle as shown in the table.

The algorithm takes a "wrong turn" at step 6, but it successfully corrects this by backtracking. The answer to the eunuch's puzzle is equivalent to the solution of the maze below.

It should be emphasized that the algorithm does not require this graph to be drawn in advance; instead sections are explored as needed.

CURRENT POSITION	POSSIBLE MOVES	COMMENTS	MOVE MADE
[ECNS || –]	[CS || EN]	starting position	[CS || EN]
[CS || EN]	[ECNS || –] [ECS || N]	old position forced by algorithm	[ECS || N]
[ECS || N]	[CS || EN] [C || ENS] [S || ECN]	old position random choice of available moves other possible choice	[C || ENS]
[C || ENS]	[ECS || N] [ECN || S]	old position forced by algorithm	[ECN || S]
[ECN || S]	[C || ENS] [N || ECS]	old position forced by algorithm	[N || ECS]
[N || ECS]	[ECN || S] [ESN || C] [EN || CS]	old positon random choice (bad move, but it shows how the algorithm copes) other possible choice	[ESN || C]
[ESN || C]	[N || ECS] [S || ECN]	old position forced by algorithm	[S || ECN]
[S || ECN]	[ECS || N] [ESN || C]	old position old position	backtrack to step 7
[ESN || C]	[N || ECS] [S || ECN]	old position old position	backtrack to step 6
[N || ECS]	[ECN || S] [ESN || C] [EN || CS]	old position old position forced by algorithm	[EN || CS]
[EN || CS]	[N || ECS] [– || ECNS]	old position forced by algorithm (finish)	[– || ECNS]



zle Solver," granted Theseus, admiring the Minotaur's elegant algorithmic solution to the eunuch's puzzle. "But what we really need is a universal method that gets us out of any maze whatsoever and doesn't involve making any marks on the walls of the labyrinth."

"Not a chance," teased the Minotaur. "Nobody would be able to pronounce the UMTGUOOAMWADIMAMOTWOTL algorithm."

"Sarcastic beast, aren't you," snarled Theseus. Then he leaped to his feet in excitement. "Wait! Your long sequence of letters has given me an idea. I know there always exists a finite sequence of left and right turns that will get you out of any particular maze. Maybe there's a sequence of left and right turns that gets you out of any maze whatsoever. Just one sequence—the same for all mazes! Something like LLLRRLRLRRLRRRRRL... but going on forever. I'll call it the TUMS algorithm—Theseus' Universal Maze Solver. I'll patent it and make millions of drachmas!"

"Nonsense!" scoffed the Minotaur. "For a start, some junctions might have more than two alternative paths. If you need to go straight on, then a choice of only left or right won't help, will it? And what happens at dead ends?"

"Good point," Theseus conceded grudgingly. "But hold on! You're wrong about the multiple junctions and dead ends, Minotaur. The choice will be just between 'right' and 'left,' provided exactly three tunnels meet at each junction: the one you approach the junction by, plus two others that fork."

"But there may not always be three," protested the Minotaur.

"Ah, but I can reduce any graph, and hence any maze, to one that has only triple junctions. I just replace a multiple junction by a ring of linked triple junctions. I can also add a closed loop to every dead end. Oh, and if there's a 'fake' junction at which only two edges meet, I delete it. Now from any graph I can produce a modified graph with only triple junctions. If I can traverse the modified graph, then I can easily reconstruct a way to traverse the original graph by contracting my additions down to points."

That got rid of the Minotaur's objection, but Theseus still had to overcome one minor difficulty: finding a universal maze-solving sequence of left and right turns. After some thought he suggested, "Suppose I produce a list of all possible mazes that contain only triple junctions."

"It'll have to be a very long list," said the Minotaur doubtfully.

"Infinite! But I need such a list only in principle, my two-horned friend. There must be some way to do it: start with the simplest maze and build up to more complicated ones in all possible ways."

"Yes! Yes!" cried the Minotaur, eyes sparkling. "I'm beginning to see it now! First you list all mazes—graphs, that is—with two nodes, then those with three, then four and so on—counting only the graphs that have triple junctions, of course. Then you string all the lists together, one after the other."

Theseus wondered whether that was possible. "What if there are infinitely many graphs for some number of nodes? Then your list goes off to infinity, and there's nowhere 'after' it to stick the next list on."

"Yes, Theseus, but the number of distinct graphs with a given finite number of vertices is always finite."

"Why?"

"You can represent any graph of n nodes by a matrix consisting of n rows and n columns. First you number the nodes from 1 to n. Then, if node a is joined to node b, you enter the value 1 in row a and column b of the matrix. Otherwise you fill that position in the matrix with the value 0. When you determine all the values in each row and column, the matrix completely specifies the topology of the graph. The number of possible matrices that can arise from a graph of n nodes is at most 2 to the power of n squared. Hence, the number of matrices is large but finite."

"Precisely," Theseus agreed. "And if the number of incidence matrices is finite, then the number of topologically distinct graphs of n nodes is smaller than that, hence also finite. If we select only those graphs with triple junctions, it makes the number of graphs even more finite—if you catch my meaning."

"Exactly. Yes, we're on to something. I see it all now. Enlighten me, Theseus."

"Well, when you've listed all the possible maze-graphs like this, you look at the first one, choose a starting place and an exit point in it, and work out what sequence of lefts and rights will get you to the exit. The sequence will be finite."

"Yes, but what if you start somewhere else in the maze? Or need to find a different exit?"

"That's the clever bit. You choose a different start and exit in the first graph and trace out where the previous sequence would have got you if you hadn't been in the place you'd originally started from."

There was a long pause while the Minotaur digested this. Theseus was about to speak when, surprisingly, the Minotaur interrupted.

"If that gets you out, fine; if not, add on another sequence that will. Do you continue to find sequences for all the other combinations of starting points and exits in the first maze?"

"Yes. Sure, there's probably a more efficient way, but it works. And when you've finished that, go on to the second maze and extend the sequence to deal with all possible starting points and exits, one after the other, and then the third maze and so on."

"Won't it take an awfully long time to list all those mazes, Theseus?" asked the Minotaur hesitantly.

"That's the best part. We can follow the sequence of lefts and rights at the same time as we work out the list. Let's start with LL. Do you see the exit?"

"Just more tunnels."

"No problem. Let me see... LRRR."

"More tunnels. But I suppose we're making progress...."

"... LRRRLLRLRRLLL," faltered Theseus, a month later.

The Minotaur's voice was gloomy. "No exit yet. How complex a maze does your list now represent?"

"Eleven junctions. I think we've found the flaw in my method—the labyrinth probably has hundreds of junctions. We may never get out of here. Wait! Do my eyes deceive me? It's my piece of string! I've found it again!"

As they followed Ariadne's thread, the Minotaur mused, "You know, I've just remembered that a quite efficient way to exit a maze is to make random moves."

"Fine time to tell me that," Theseus retorted. "I see the light at the end of the tunnel."

The Minotaur congratulated Theseus and departed immediately for greener pastures. The hero walked to Minos' palace, where he found Ariadne sleeping. With a passionate embrace he awakened her. "Oh, my darling Theseus!" she exclaimed. "I knew my string would save you!"

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BOOKS

Did the U.S. government set up a top secret UFO Working Group?

by Philip J. Klass

OUT THERE: THE GOVERNMENT'S SECRET QUEST FOR EXTRATERRESTRIALS, by Howard Blum. Simon and Schuster, 1990 ($19.95).

If author Howard Blum, a former reporter with the *New York Times* and *Village Voice,* had labeled his new book "fiction," he might be characterized as an "aspiring young Tom Clancy," and *Out There: The Government's Secret Quest for Extraterrestrials* might have been as exciting as *The Hunt for Red October.*

Deep inside Cheyenne Mountain near Colorado Springs, where the North American Aerospace Defense Command (NORAD) and the U.S. Space Command personnel monitor a global network of satellites and ground-based radars designed to warn of enemy missile or bomber attack, suddenly an unknown object is detected performing extraordinary maneuvers in space. The object is spotted by the Naval Space Surveillance System, an "electronic fence" that stretches across the nation's southern states from the Atlantic to the Pacific.

As a result, the Pentagon's Defense Intelligence Agency (DIA) enlists the help of three "viewers" with "psychic powers," who earlier demonstrated their ability to "see" distant submerged Soviet submarines to pinpoint their locations. The psychics are asked to apply their powers retroactively—that is, to try to see the object that 48 hours earlier had passed through the Navy's surveillance system. All three psychics succeed and draw sketches that show a traditional flying saucer.

This prompts the DIA to create a top secret "Unidentified Flying Object Working Group" whose very existence must be kept from the public. Presumably, it would be terribly embarrassing for the Pentagon to admit it goofed nearly two decades earlier when it closed down its Project Blue Book UFO investigative effort because the 17-year program had not turned up any evidence of visiting extraterrestrial craft.

While Tom Clancy probably would find Blum's plot too far out, he might kick himself for letting Blum beat him to the punch with a novel involving an intelligence agency, flying saucers and psychics. But in Blum's opening "Note to the Reader," he claims: "This is a true story. I verified every name, incident, date, and conversation that is recorded in this account."

For this reviewer, it was quickly apparent that this brash claim is hogwash—even before investigating some of his others. The reason is a short chapter that Blum devotes to a not unflattering account of my career as a UFO debunker and technical journalist. In this chapter's seven pages, I counted 25 errors of fact.

According to the book's jacket blurb, "for years, the United States government has repeatedly denied reports of any official interest in UFOs or of any covert military investigations into the possibility of life on other planets. In an extraordinary feat of investigative journalism, award-winning former *New York Times* reporter Howard Blum has uncovered the truth: the U.S. government is lying."

Out There, the blurb continues, "reveals the existence of the top-secret UFO Working Group, established in December 1987, whose members—intelligence officials, scientists, military officers—meet regularly at the Pentagon to evaluate UFO sightings." Blum says that two members of this 17-man group served as his sources. Their memories seemingly are good enough to provide colorful verbatim dialogue but not good enough to enable Blum to give the dates when the meetings were held.

According to Blum, his sources will-

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ingly supplied him with details on their top secret deliberations but not the names of any of the group's members, except for its chairman—Army Colonel Harold E. Phillips. Blum claims that he talked briefly by telephone with Phillips in his Pentagon office. But the Army says it has no record of a Col. Harold E. Phillips on active duty during 1987–1989, when Blum says Phillips was assigned to the DIA in the Pentagon. Nor do the Pentagon telephone directories for that period show any Col. Harold E. Phillips.

To ascertain that I was not the victim of a Pentagon disinformation cover-up, I made an independent check. Blum reports that Phillips, born in 1941, graduated from the University of Southern Illinois (actually Southern Illinois University) with a degree in engineering. When university officials checked, they could not find any person with that name who had attended that institution in the late 1950s or the 1960s, let alone having graduated with an engineering degree. Despite Blum's boast that he "verified every name," my investigation indicates that Phillips—the centerpiece of much of the book's tale of the government's alleged top secret UFO activities—does not exist.

The same is true for another of Blum's principals: Commander Sheila Mondran. According to the book, Mondran was on duty in the Cheyenne Mountain facility in December 1986 and watched the flying saucer's extraordinary maneuvers on a display terminal. At my request, Space Command checked its records, and its public affairs officer, Major Tom Niemann, informed me that there had never been a Cmdr. Sheila Mondran assigned to the Space Defense Center nor had any other female Navy commander during 1986–1987. Out of curiosity, Niemann said he checked the Navy, and it too was unable to find any record of an officer named Sheila Mondran.

This came as no surprise because Blum's account, seemingly based on an interview with Cmdr. Mondran, was riddled with errors. Blum claims that after Mondran arrived inside the Cheyenne Mountain complex, "she took a polished steel elevator down to the third level, *descending almost 2,500 feet* [emphasis added]." There is no such elevator—only a freight elevator that goes *up* three levels.

More important, even if a flying saucer had performed extraordinary maneuvers as it passed through the Naval Space Surveillance System, the system is not designed to detect such acrobatics. Its function is simply to detect each space object passing through its elec-

tronic fence and log its approximate altitude, longitude and time of passage.

These data are correlated with the expected time of passage and location of previously catalogued space objects. If a satellite should explode because of an on-board malfunction, previously uncatalogued fragments will be detected, which analysts then try to correlate with the now "missing" spacecraft.

I asked Space Command's Niemann whether any mysterious "Uncorrelated Targets" (UCTs) had been detected by the Navy's system during December 1986, when the UFO incident allegedly occurred. He checked and told me that there had been only one UCT during the entire month, on December 4. But Niemann added that a Viking rocket booster in orbit had broken up into approximately 400 fragments several weeks earlier. The single UCT detected in December was "considered insignificant and not noteworthy because it was presumed to be one of those several hundred fragments," Niemann said.

Blum's assertion that Mondran watched the flying saucer's maneuvers on a display in the Cheyenne Mountain complex is spurious. The Navy's system does not provide the Cheyenne Mountain center with a "real-time" display of objects passing through its electronic fence.

Blum claims that as part of his research into UFOs, he visited the former Project Blue Book offices for UFO investigations at Wright-Patterson Air Force Base in Dayton, Ohio. He states that "the headquarters of Project Blue Book had been lovingly preserved."

For most of the 20 years that the Air Force had investigated UFO reports, the task had been an unwelcome assignment that evoked much criticism. It would be as if former President Richard Nixon chose to "lovingly preserve" the rooms involved in the Watergate break-in that led to his resignation.

Blum describes the Project Blue Book headquarters as being "a small, gray room cluttered with...empty desks.... [A]gainst one battleship-gray wall there was an impressive line of filing cabinets. *Hundreds of drawers* [emphasis added]." A simple calculation shows that if there were 300 drawers (60 file cabinets) they would extend for 75 feet. Yet Blum describes the room—which would be one quarter the length of a football field—as "small."

If the Project Blue Book offices were as "lovingly preserved" as Blum contends, and if he had visited them, he would have had to make arrangements through the public affairs office at Wright-Patterson. When I inquired of that office, I learned that no one knew where the offices were located or had been located 20 years earlier.

If a UFO Working Group were created as Blum claims, it is the most inept operation ever conducted by the Pentagon or any other government agency. To characterize it as a Keystone Cops operation would be a massive understatement.

One of Col. Phillips's most challenging problems, according to Blum, was to "find the one [UFO] sighting that he could present to the Working Group as 'highly promising,' as the plausible candidate for in-depth analysis." Seemingly, Phillips completely forgot the UFO that (allegedly) performed acrobatics while passing through the Navy's electronic fence, which (allegedly) had prompted the DIA to create the UFO Working Group.

In early 1988, Blum reports, Phillips became "convinced he had found his investigative target in Gulf Breeze, Florida. The sightings in this southern town were shared by a variety of witnesses, and there was even a blurred film of what many responsible observers swore was a UFO. But this candidate fell by the wayside after the colonel had some preliminary discussions with friends at Air Force Intelligence. It turned out the Air Force was testing a classified low-flying surveillance plane in the area."

If Phillips had invested $25 to subscribe to the *MUFON UFO Journal*, published by the nation's largest UFO group, he would have seen many of the roughly two dozen Gulf Breeze UFO photographs—all taken at night or in near-darkness. They show a saucer-shaped craft with illuminated portholes—hardly the sort of vehicle the Air Force would design for covert low-altitude surveillance.

The photographs were taken with an older Polaroid camera whose film remains in the camera until manually pulled down, making it very easy to create double-exposure hoax pictures. The man who took the photographs, who had earlier served time in prison for forgery and car theft, claimed he received ESP messages—often in Spanish—from the UFO, as well as images of nude women. (In early 1990 a small model resembling the UFO in the photos was discovered hidden in the attic of his former residence.)

Undaunted, Col. Phillips found "another promising candidate—the Hudson Valley sightings...[which] had been independently affirmed over the past two years by a variety of unimpeachable, upstanding sorts, an eclectic group that included IBM engineers, housewives, and schoolteachers. But then, just when Colonel Phillips was on

the verge of recommending that the Working Group dispatch a photographic team to the [area]…a discouraging report crossed his desk. According to an investigation by a local newspaper, the UFOs were nothing more than convoys of small planes flying with their nighttime running lights on."

If Phillips had enlisted the aid of one of the DIA's reference librarians when he first became interested in the Hudson Valley UFO case, he could have learned that it had been exposed as a hoax more than three years earlier. An investigation by *Discover* magazine revealed that a group of daredevil private pilots was responsible, and the exposé was featured in the November 1984 issue of the magazine.

After these experiences, according to Blum, Phillips recognized that any UFO case which he recommended for in-depth analysis had to be "unblemished. Too much was at stake. Finally, early in the summer of 1988, Colonel Phillips… [announced] that he had at last isolated what he called the 'perfect candidate.' The witnesses, he explained, were not one or two or even a handful of people—but an entire town."

The town was Elmwood in west central Wisconsin, population 991. Through the years many of its citizens had reported seeing UFOs, prompting Elmwood to hold a "UFO Days" tourist festival every summer. The town achieved international fame when its mayor announced plans to build a $50-million landing field for UFOs—if funds could be raised. (They couldn't.)

Phillips decided to send two covert agents to Elmwood. As luck would have it, they arrived in time for the UFO Days festivities. In keeping with the Keystone Cops modus operandi of the Working Group, the agents were instructed to pose as NASA engineers, according to Blum. This was a dumb "cover" because the space agency has never had any official interest in UFOs.

If Phillips believed that Elmwood offered the most impressive evidence for extraterrestrial visitors that the UFO Working Group had found after more than a year of effort, then clearly it was a place that Blum should visit, and he did. Blum devotes nearly one sixth of his book to recounting his experiences there.

In the book's final pages, Blum wonders whether his tale might "seem too novelistic? Would readers understand that seemingly casual details—the shopping spree that delayed Commander Mondran…were rock-solid facts excavated from mountains of research and observation and not simply an unscrupulous author's easy inventions?"

ESSAY

The risks in cutting funds for space programs

by Bill Nelson

America's space program was shifted into a lower gear last fall by a scant seven pages in a slim congressional budget document. In essence, the National Aeronautics and Space Administration was ordered to dampen its wide-ranging dreams with a splash of fiscal reality. Instead of struggling to fund an ever expanding agenda with an inadequate budget, NASA was directed to curtail new projects and scale down existing ones.

These fiscal restraints are unlikely to be changed by the recent recommendations of the Advisory Committee on the Future U.S. Space Program, established last summer by Vice President Dan Quayle. The report calls for a more research-oriented NASA, founded on more stable funding, a scaled-back space station, a new heavy-lift launch vehicle for unmanned payloads and a space shuttle that emphasizes scientific studies. These are solid suggestions to guide America's space future.

Still, recommendations are not political reality. It will be up to the Bush administration and Congress to use the report as a base on which to build political coalitions that support implementation. In the meantime, the current reduction in NASA funding without long-range direction places more at risk than the scientific value of aggressive space exploration. Slowing space research will dull America's technological edge. And, in a less tangible way, it toys with what has become an essential element of the nation's standing in the world.

Just 18 months ago NASA's future seemed well defined. President George Bush set a goal of renewed human exploration of the moon and a manned mission to Mars in the next century. Construction of the space station *Freedom* was deemed essential to that goal. Congress also gave special consideration to NASA with annual budget increases of 15 to 20 percent.

It is not that Congress now wants to scale down NASA, which enjoys broad popular support. It is well aware that slowing development of the space station will affect the U.S.'s international partners, who plan to attach their own research modules to the orbiting laboratory. Congress also knows that space spending is a good investment, returning seven dollars to the economy for every dollar spent on R&D.

But the deepening deficit crisis, coupled with the five-year guidelines set forth by the president and congressional leaders for reducing the budget, has made the future starkly clear. The space program can expect its budget to increase 10 percent annually at best, with much of that eaten by inflation.

The most immediate change will affect the space station. Instead of assembling an orbiting laboratory able to house a permanent staff right away, the U.S. will follow the Soviet Union's example of incremental growth. This change is hardly the first attempt to reduce the station's cost. As recently as a year ago, the space station team reacted to budget pressures and looming cost overruns by delaying development plans and curtailing some goals.

NASA's management of the station and its inability to define the station's capabilities have no doubt added to the funding problems. In the six-year history of the space station program, there have been 12 major program reviews, four NASA administrators, five assistant administrators assigned to the program and six program directors. Cost projections have almost doubled. The uncertainty surrounding NASA's annual budget request has made the situation worse. To accommodate the annual budget process, for instance, new financial commitments and some work are regularly delayed in midsummer while program managers wait for a clear indication of the next fiscal year's budget.

To improve NASA's fiscal management, Congress and the president must change how they fund the agency. All parties must agree to begin multi-year financing of its major science programs. Research and development of new technology often take a decade, and associated costs are tremendously difficult to predict. If a steady funding stream can be counted on, the seemingly inevitable cost overruns can be better managed. The only time this concept was implemented proved to be a stellar success. Congress and the White House approved a lump-sum budget of $2.1 billion in 1987 to construct an orbiter to replace the *Challenger*. Delivery is expected on time this coming May—at $300 million under budget.

The Space Science and Applications Subcommittee in the House has attempted to lead the way. Beginning in 1989, the subcommittee and its parent committee began approving three-year authorization bills for many NASA programs. Two voices do not make a chorus, however. Stiff-armed rejection of the concept by the Senate authorization committee and the House and Senate appropriations committees that actually approve final budgets halted the effort.

Ironically, the reduction of NASA's budget mandated by the five-year budget growth limit may result in a de facto multi-year appropriation. NASA's overall revenues will be spelled out for the next five years, albeit in rather bleak language. Allocations to various programs, however, will remain open to the annual vagaries of Congress. To clarify their commitment to these programs, appropriators should set multi-year budgets for NASA's major initiatives.

This action would derive benefits far beyond the stability it would bring to U.S. space efforts. A more solid set of goals, priorities and funding levels will shore up the nation's reputation as a reliable partner in international research. A predictable program will be a clear sign to future engineers and scientists that jobs in high technology exist if they choose a career in the sciences.

At a time when the percentage of students who are pursuing a science degree has dropped from 11.5 percent in 1966 to 5.8 percent in 1988, some visible encouragement is needed. The current predictions point to a shortage of 675,000 scientists and engineers by the year 2000. Ongoing efforts to attract more students into these fields must be substantiated with the assurance that a robust scientific community will exist when they graduate. Charts tracking space spending with the number of doctorates in the hard sciences show a direct correlation. A strong space program does attract students to careers in technology and research.

America must expand its technological prowess. Spending a predictable amount on space endeavors can provide an immediate payoff of new technology as well as seed the nation's universities with students embarking on careers in science. The changes needed to make this happen are easily implemented. Stable and adequate space program financing must be provided if the U.S. is to prosper in the world economy of the 21st century.

BILL NELSON, former Congressman from Florida, chaired the House Space Science and Applications Subcommittee.

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