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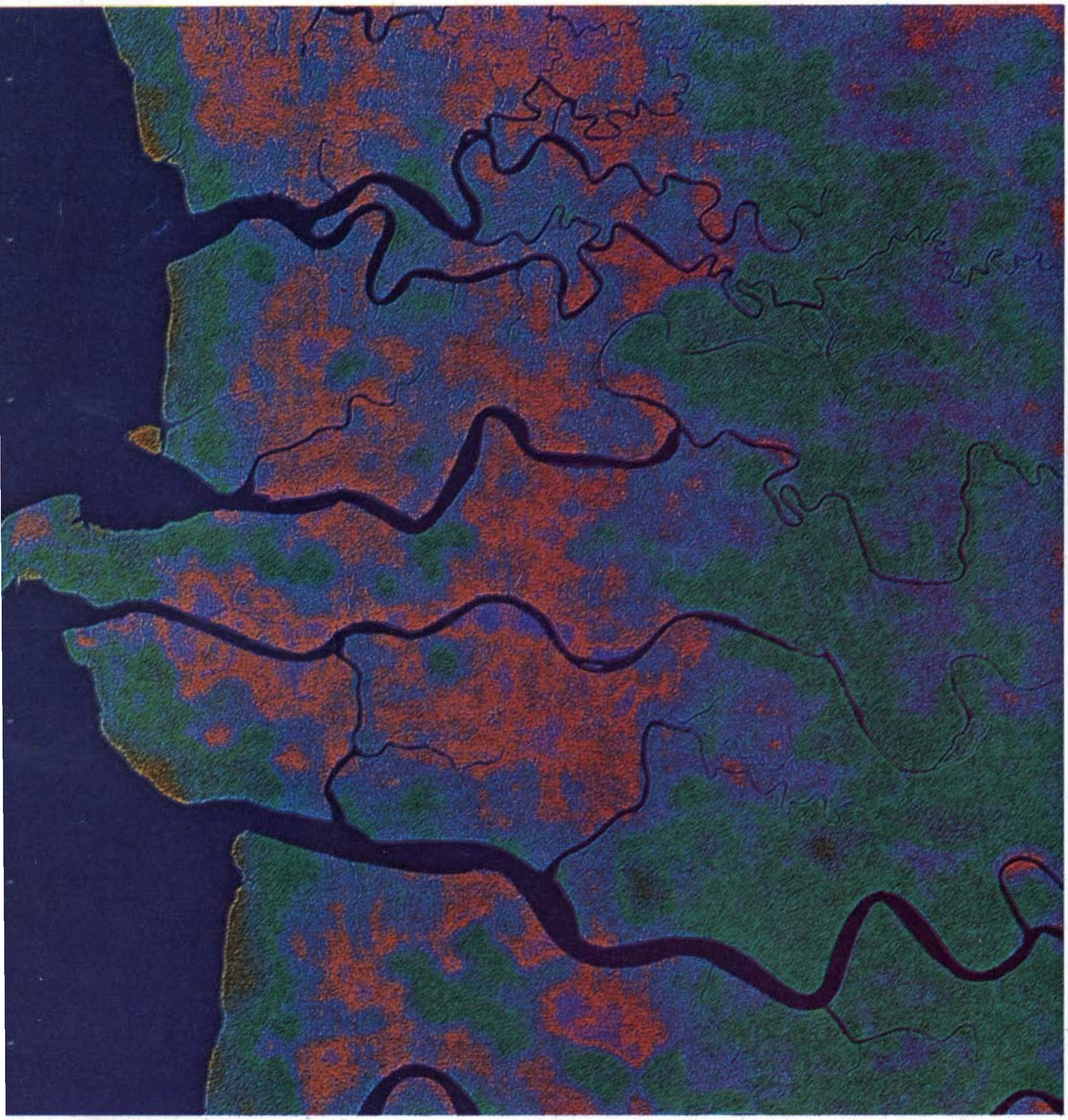

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December 1982

American Driving Machine Performance Report.

- ☑ Advanced front-wheel-drive performance.
- ☑ Rated over Mercedes 300D for overall driving superiority by 38 out of 50 automotive engineers.
- ☑ Sports sedan suspension and 5-speed manual transmission.
- ☑ 38 est hwy. [23] EPA est mpg.*

Cars that combine sports car performance with family car room fit into an exclusive category known as sports sedans. Traditionally, (like BMW, Audi and Mercedes) they came from Europe. Until the new 1983 Dodge 600ES. It's the American alternative that rivals Europe's best.

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When 50 automotive engineers compared the Dodge 600ES to a Mercedes 300D, they preferred the 600ES 38 to 12 for overall driving superiority after making comparisons and evaluations of maneuverability, cornering, pickup and acceleration.

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The roomiest, high gasoline mileage six passenger car in Americ Dodge 600. 32 est. hwy. [24] EPA est. mpg.* $8,841.**

*Use 23 and 24 EPA est. mpg. for comparison, your mileage may vary depending on speed, weather and trip length. Actual hwy. mpg. probably lower.

give up the comfortable ride and room of a family size car.

And the 600ES also has some sophisticated electronics that you won't find in any European sedans. Like a voice alert system that keeps you informed about 11 vital functions.

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The 600ES is the affordable American alternative for those smart money people who don't want to pay the price of a house in the country for a car. You can own this fine American sports sedan for as little as $9,372.**

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ARTICLES

DEPARTMENTS

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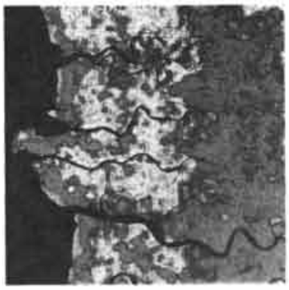

THE COVER

The picture on the cover is a false-color radar image of a swampy coastal region in western New Guinea. It was made by an advanced radar system that was carried into orbit last year on board the space shuttle *Columbia.* The spaceborne radar, called *SIR-A* (for *Shuttle Imaging Radar-A*), represented a new class of remote-sensing devices that are extending the study of the earth's surface from orbiting spacecraft into the microwave region of the electromagnetic spectrum (see "Radar Images of the Earth from Space," by Charles Elachi, page 54). An imaging system of this type is termed a side-looking, synthetic-aperture radar; it operates by directing a beam of microwaves obliquely onto the earth's surface and then detecting the backscattered signals received by the radar antenna as the spacecraft moves along a well-defined track; an image of each point on the surface is synthesized after the fact by processing the signals recorded at each orbital position for which the point is within the illuminating microwave beam. Colors can be added to the image later to enhance slight differences in the intensity of the backscattered radiation. In this case the oceans and rivers are dark blue and the land is variegated, probably owing to differences in the density and the texture of the vegetation. The image was recorded as the shuttle was moving in a southeasterly (*downward*) direction at an altitude of about 250 kilometers over the ocean southwest of the coastline. The regularly spaced dots along the left margin are an artifact of the imaging process.

THE ILLUSTRATIONS

Cover photograph courtesy of the Jet Propulsion Laboratory, California Institute of Technology

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LETTERS

Sirs:

Owen Gingerich's article "The Galileo Affair" [SCIENTIFIC AMERICAN, August] contains some philosophical and historical howlers that produce more smoke than light. Philosophically one can ask: Does science search for truth? For Gingerich, Galileo is a hypothetico-deductivist and hence must answer no, since science can only prove hypotheses false, never true. If this is right, then "mirabile dictu" Galileo and Bellarmino never had a disagreement, since the latter granted to Galileo all that the h-d theorist requires, namely that the Copernican system saves the appearances. But surely this is madness! Galileo maintained that the heliocentric theory was true. He opted for a heroic and, by my lights, a correct strategy that assumed the truth, achieved with or without the hypothetico-deductive method, is the sole concern of the scientist.

BRENDAN MINOGUE

Associate Professor
Philosophy and Religious Studies
Youngstown State University
Youngstown, Ohio

Sirs:

It is one of the crueler ironies of the "Galileo affair," curiously unmentioned by Gingerich, that although we have come to accept a world picture very like the one advocated by Galileo, we have nonetheless accepted an epistemology and methodology of science that is much closer to Cardinal Bellarmine's than to Galileo's. With Pope Urban, we incline to the view that the post hoc confirmation of a theory can never establish its truth or rule out a plethora of rival theories. . . .

LARRY LAUDAN

Virginia Polytechnic Institute
and State University
Blacksburg

Sirs:

Toward the close of his interesting article "The Galileo Affair" Owen Gingerich concluded that the way the modern Catholic church could benefit from its unfortunate dealings with Galileo would be now to accept "Galileo's arguments about the reconciliation of science and Scripture. The truth of the Bible . . . must not be found in a literal six days of Creation, in the sun standing still. . . . Such a judgment, it seems to me, would confirm what has long since been accepted by both Catholic and Protes-

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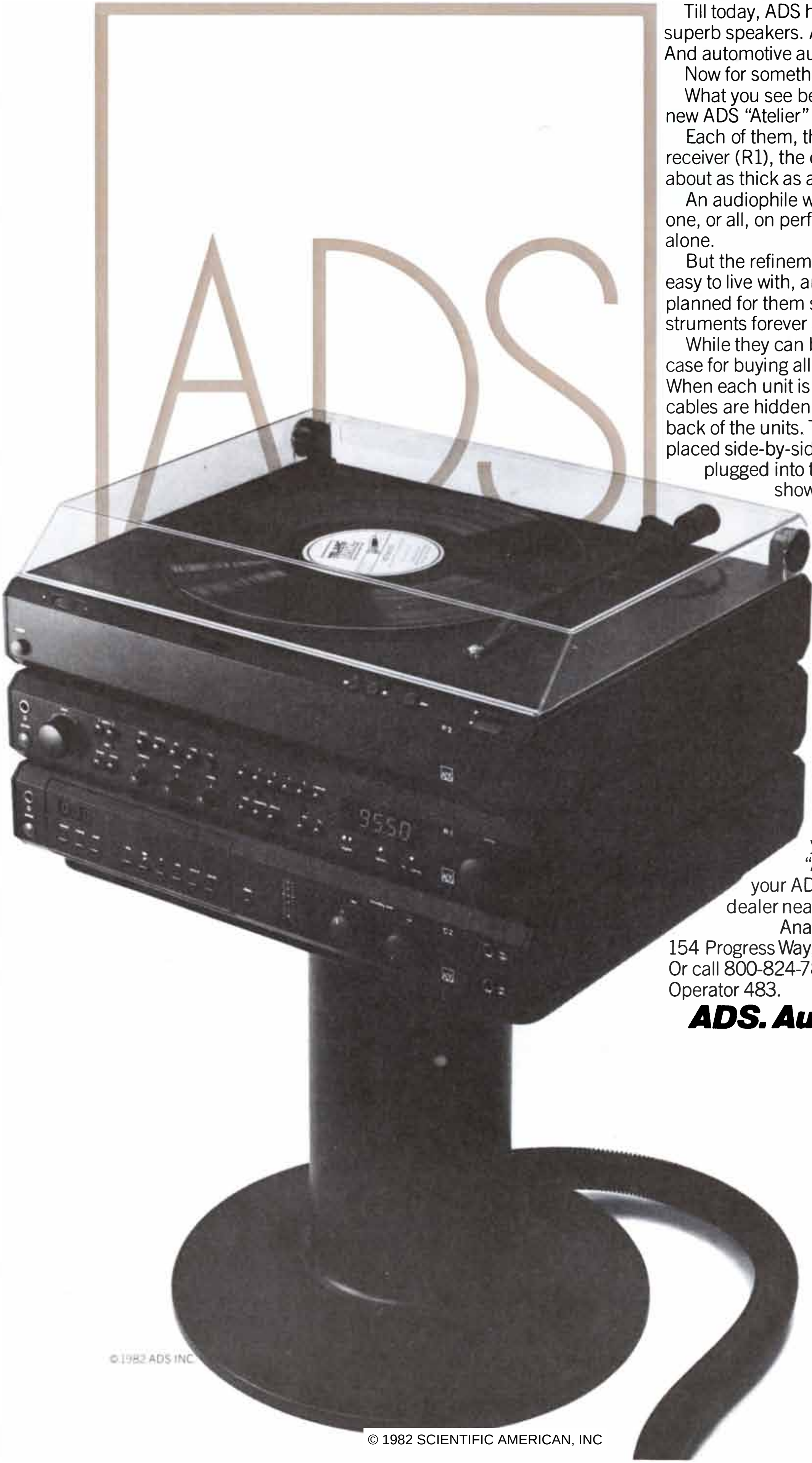

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tant theologians. It would also speak to the current controversy over Darwinian evolution and the so-called Creation science."

But in fact the Catholic church *officially* adopted this approach nearly 100 years ago when Pope Leo XIII wrote: "The sacred writers [of the Bible]... did not seek to penetrate the secrets of nature but rather described and dealt with things in more or less figurative language, or in terms which were commonly used at the time.... Ordinary speech primarily and properly describes what comes under the senses; and somewhat in the same way the sacred writers—as the Angelic Doctor [St. Thomas Aquinas] also reminds us—'went by what appeared to the senses' (*Summa Theologica* I, 70, 1, 3) or put down... what men could understand and were accustomed to" (*Providentissimus Deus,* 1893).

Leo's pronouncements were confirmed and furthered by Pope Pius XII in 1943 in *Divino Afflante Spiritu,* by the Second Vatican Council (1963–65) and more recently by Pope John Paul II in his Albert Einstein commemorative address to the Pontifical Academy of Sciences (November 10, 1980).

RICHARD W. CLINNICK, PH.B., M.A.

San Ramon, Calif.

Sirs:

Owen Gingerich renders the name Accadèmia dei Lincei as Academy of the Lynxes. This is a natural error, but in fact the name means Academy of Lynceuses, that is, people like Lynceus. Lynceus is an obscure (to us) mythological character, one of the Argonauts, who had telescopic and X-ray vision; he could see to any distance and right through the earth. We may think of the lynx as being sharp-eyed, but I cannot find any classical reference to its having these abilities.

FRED W. HOUSEHOLDER

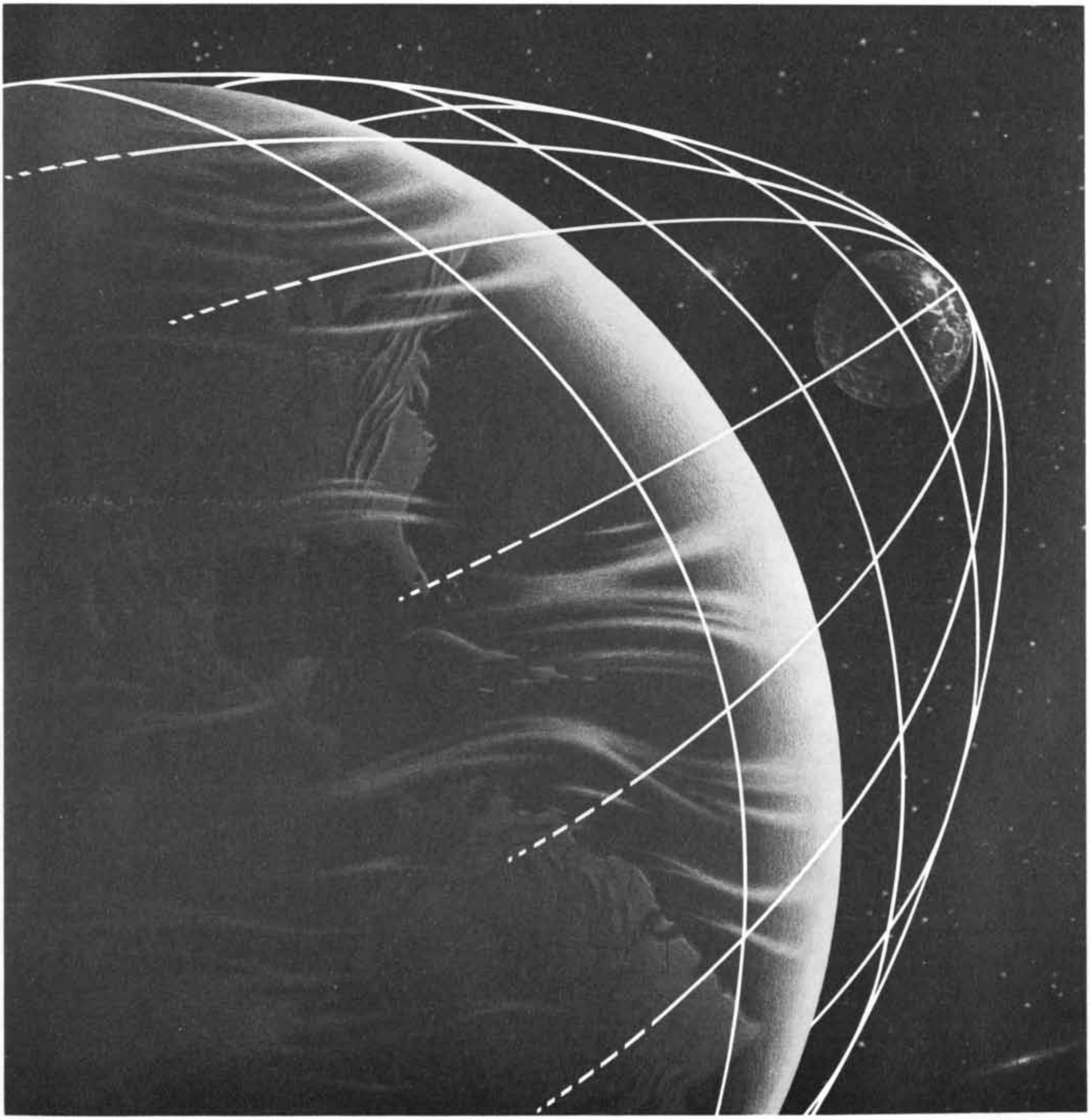
Indiana University
Bloomington

Sirs:

The Lincei, fascinated by puns, may well have known about Lynceus in choosing their name. They did, however, adopt the lynx as the symbol for their academy. Later in the 17th century the astronomer Johannes Hevelius designated a group of faint stars as the constellation Lynx, remarking that one must be as sharp-eyed as a lynx to actually see the configuration.

OWEN GINGERICH

Cambridge, Mass.



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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1932: "Jobs for 12,000 men are expected to result from a loan of $62,000,000 recently authorized by the Reconstruction Finance Corporation for the construction of the San Francisco–Oakland Bridge. The State of California is to provide the remainder of the $70,000,000 necessary and will maintain and operate the bridge. Tentative plans call for a central span that will be something like 1,000 feet longer than that of the George Washington Bridge over the Hudson River, which now holds the world record."

"The solar corona is always there. So are the prominences. All that prevents our seeing them is the bright foreground of sunlit air through which we look. To penetrate this foreground Bernard Lyot has designed a new type of telescope. By the choice of an exceptionally fine disk of glass and by careful polishing, defects on the surface or in the interior were eliminated. The light unavoidably scattered at the edge was got rid of very cleverly. An auxiliary lens inside the tube of the instrument formed a real image of the objective on a screen pierced with a hole slightly smaller than that image. The objectionable scattered light was thus caught, while almost the whole of the useful rays passed through. With this instrument Lyot has succeeded in reducing the apparent brightness of the sky to only 1/250,000 of that of the sun's disk. The solar prominences are directly visible on any clear day. Perhaps the most noteworthy of all Lyot's successes is the observation of the lines of the coronal spectrum. Feeding the light from his 'coronagraph' into an equally well-designed spectroscope, he has photographed bright lines in the green at 5,302.85 angstroms and in the red at 6,374.75 angstroms, which agree excellently with the strongest of the known coronal lines."

"Just five years ago the United States witnessed completion of one of those great pioneering efforts—the good-will flight of the United States Army flyers who succeeded in the first flight around the South American continent. They had made a remarkable journey, a 20,000-mile flight to the 21 Pan-American nations, and in the face of terrific obstacles accomplished it in some five months. There was then no one optimistic enough to venture the opinion that within 10 years those same great stretches of jungles, mountains and open sea traversed by the Army flyers would be flown by commercial airplanes. Yet today big American transport planes fly regularly over every foot of the territory covered by those good-will flyers. Through a highly co-ordinated system of 22,000 miles of airways the United States is linked directly with 32 countries and colonies in the Western Hemisphere. Land-plane equipment, including a fleet of Wasp-powered F-10-A's and Ford tri-motors, is operated on schedules requiring an average speed of 115 miles per hour. Marine equipment, which includes 35 Wasp-powered Sikorsky S-38's and Hornet-powered Consolidated Commodore flying boats, both types bi-motored, is scheduled at 100 miles per hour. To date the Pan-American Airways System has carried more than 130,000 passengers and has flown 32,419,349 passenger-miles."

SCIENTIFIC AMERICAN

DECEMBER, 1882: "Iron, tough and true, the weapon, the tool and the engine of all civilization, is now fairly displaced by its younger rival, mild steel. For all shapes that can be rolled this revolution is accomplished, and in forged work of small size the change is hardly less complete. This is especially true of railroad work, and not only rails, tires, axles, bolts, rivets and boiler plate but also pistons and connecting rods, all forged parts of the valve gear and minor parts of the engine are now made in this tougher, stronger and more uniform and reliable metal. In 1870 we in the United States were making somewhere around 20,000 tons of steel, in 1873 about 160,000 tons and to-day about a million and three-quarters tons."

"Last month was characterized by many wide-spread electrical disturbances, which culminated in intensity on November 17. On that day telegraphic communication was more or less interrupted over the northern half of the United States, and much damage was done to switch boards and other telegraphic apparatus. The disturbance extended across the sea, interfering seriously with the work of the cables, and made itself felt in many parts of the European continent. Brilliant auroras were generally seen where the sky was clear. The appearance of exceptionally large sun spots is believed to have more than an accidental connection with these disturbances of the earth's electric equilibrium."

"Mr. H. M. Stanley has had practically unlimited means at his command through the generosity of the King of the Belgians. The object of the King appears to have been simply to do what he could to render accessible to commerce and civilization, and thereby to develop, the resources of the great interior of Africa. For this purpose the Congo formed a splendid channel of communication. Mr. Stanley has done some good exploring work some 400 miles above Stanley Pool, 700 miles above the mouth of the river. In his opinion the soil is capable of unlimited crops of all kinds, and the supply of caoutchouc in the forest is inexhaustible. The greatest difficulty to the utilization of the river throughout its navigable length is the almost untamable cannibal tribes that inhabit the upper reaches between Stanley's farthest point and the neighborhood of Nyanginé."

"At the age of 82 years, after a life actively devoted to scientific work of the highest and most accurate kind, which has contributed more than that of any contemporary to establishing the principles on which the exact science of chemistry is founded, the illustrious Friedrich Wöhler has gone to his rest. Until the year 1828 it was believed that organic substances could only be formed under the influence of the vital force in the bodies of animals and plants. It was Wöhler who proved by the artificial preparation of urea from inorganic materials that this view could not be maintained."

"The English sparrow was first introduced to this country in 1862. The importation was made solely in view of the benefit to result from the birds' immense consumption of larvae. The only positive result of their introduction is that the measuring worm, which formerly infested all our vegetation, is now very nearly extinct through the instrumentality of the sparrow. The amount of havoc in our wheat fields created yearly by the sparrows, however, is enormous. Their forwardness and activity have driven all other birds from where they have settled, so that the hairy caterpillars, which sparrows do not eat and which used to be extensively consumed by other birds, are now greatly on the increase."

"In the lower sections of Polk, Sumter, Hillsborough and Manatee counties of Florida the soil is well adapted to tropical fruit and is considered very valuable. Orange growers in the more northern portion of the state are gradually going farther south in order to get below the frost line. These lands can be utilized every month in the year. Three crops of vegetables can be raised in the 12 months, and it seems to be just the place where a lazy man can get along with the least possible wear and tear upon the conscience."


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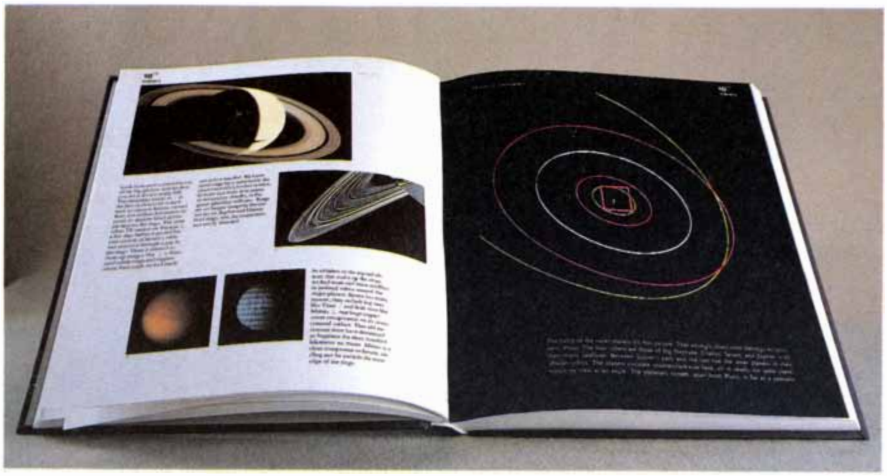

MAN'S CORNER OF THE UNIVERSE lies open here at the pages in Powers of Ten that display the universe at the 10^{13} meters dimension (10 billion kilometers), about the diameter of the solar system.

POWERS OF TEN

A wondrous journey across the universe from its largest dimension to its smallest

Here is an atlas of the universe and a handbook to its exploration by the disciplines of science. In vivid color illustration—from the informed imagination and from the instruments of science—*Powers of Ten* shows how the universe looks from the largest to the smallest dimensions now in the grasp of human understanding.

This spectacular journey, with its sweeping changes in perspective, proceeds in ordered steps, each a multiple of ten of the last step or of the next.

There are 42 of these equal logarithmic steps from the outermost regions to the innermost recesses of the known universe. More than half were taken in the lifetime of scientists now alive.

The visual magic of this first-time-in-history journey is the bold invention of Charles and Ray Eames, who have here turned their mastery of multi-media technology to book design. Your tour guides are Philip and Phylis Morrison. They supply instructive and poetic pages of commentary, answering questions and showing how the sciences get those answers at each of the 42 steps.

The SCIENTIFIC AMERICAN LIBRARY publishes *Powers of Ten* as its premier volume because it sets out the agenda of the books that are to come. Each succeeding book further illuminates the ideas and images displayed, step by step, on the pages of *Powers of Ten*.

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. . . is written by a scientist who has made his own pivotal contribution to the work on the topic;

. . . rewards its reader not with "information" but, thanks to the sympathetic collaboration of the author and editor in the preparation of text and illustration, with command of the concepts central to understanding of the work and appreciation of its meaning.

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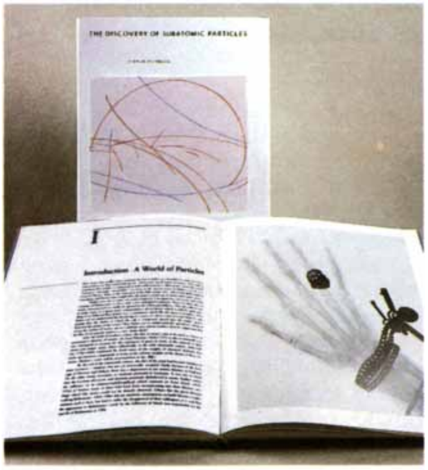
A SAMPLING OF THE DIMENSIONS of the known universe explored on the journey through the Powers of Ten is shown here. At center, the Taj Mahal adorns the 10 meter world in reach of our unaided senses. Dimensions grow smaller to the left: first, crystalline skeletons of single-celled diatoms at 10^{-4} meter (.1 millimeter) and at far left, tungsten atoms, 10^{-10} meter in diameter, brought into visibility by a field-emission microscope. At right, looking across the Indian Ocean toward the South Pole through the window of Gemini II, the curvature of the Earth, 10^{7} meters in diameter. At far right, a quasar, 10^{25} meters away (one billion light-years), caught by a radio telescope and imaged by computer graphics.

SUBATOMIC PARTICLES

by Steven Weinberg



DISSECTION OF ATOM began with accidental discovery of X-rays by Roentgen in 1895.

As everyone knows, the once irreducible atom has been shown to be composed of still more fundamental particles: the electron, proton and neutron. But how do we know this? In *The Discovery of Subatomic Particles* the reader comes to know the answer just as Steven Weinberg and other physicists did, thereby sharing in the intellectual enterprise that has reshaped physics in the twentieth century.

We do not accept scientific truth on faith or authority. We know truths of this kind are grounded on experiment and observation—operations we might have performed ourselves, but in any case can perform inside our heads. With Weinberg the reader of this book reenacts the historic succession of experiments that disassembled the atom. From each experiment to the next, the reader will gain a confident understanding of the laws of physics that govern the events encountered.

HUMAN DIVERSITY

by Richard C. Lewontin

The relevance of science to human values finds compelling demonstrations in the proper understanding of the genetics of our species. In *Human Diversity* Richard Lewontin shows that each human being differs from all others because of the interaction of genetic differences, environmental differences, and chance events that occur during development. There is no unique ''normal'' genetic constitution.

The genetic markers that supposedly divide the species into races are only a trivial fraction of the total spectrum of diversity in which each person finds singularity. The genetic endowment held in common across racial, national and cultural boundaries is a consequence of the biological history of our species. The segregation of people into social castes can never again invoke genetics as its rationalization.

FOSSILS

by George Gaylord Simpson

One of the architects of the modern evolutionary synthesis here establishes the nature—and the true splendor—of the solid evidence upon which much of the theory and the facts of evolution rest. Simpson declares: ''The primary record of the history of life is written in the successive strata of rocks as in the pages of a book. Fossils may be called the writing on those pages. Traces of organisms living at successive geological times, they represent once living things and should be seen as such. They must be put in their sequence in time. They were influenced by and bear witness to geographic and geological changes on the earth. They are basic materials for the study of organic evolution. Their study combines historical geology and historical biology into one great synthesis.''

THE SOLAR SYSTEM

by Roman Smoluchowski

The fine-grained picture of the Earth and its immediate cosmic neighborhood now in the possession of mankind is here comprehensively assembled. The author has brought together the latest graphic images from the satellites and from earthbound telescopes as well. (We know the terrain of cloud-wrapped Venus from radar echoes returned to the 600-foot radio telescope at Arecibo in Puerto Rico.) He shows us our solar system in time as well as in space. In the wealth of images of the Sun, of the planets, of their satellites, of the swarming asteroids and of the cometary messengers from the primordial ice clouds on the outermost circumference of the system, we comprehend the origin, the history and the fated future of our Sun and its planets.

MUSICAL SOUND

by John R. Pierce

In this volume, the author will share with you his joy in the discovery that understanding from physics and mathematics enlarges and enhances one's appreciation of music. Thereupon you will find yourself in the company of a long succession of natural philosophers who have pursued just that strategy.

John R. Pierce is the latest of these natural philosophers. To his work in music he brings his study of sound, its transmission and reproduction, at Bell Telephone Laboratories plus the insights of such contemporary composers as Pierre Boulez, John Cage and Edgard Varèse.

In the live recordings that come with this volume Pierce demonstrates something of what the psychology of acoustics has learned about the perception, the illusion and the effect of sound. He imbues the reader with his confidence that rational enquiry into this most intensely subjective of all aesthetic experiences will open up new realms of sound to that experience.

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THE AUTHORS

DANIEL R. VINING, JR. ("Migration between the Core and the Periphery"), is associate professor of regional science at the University of Pennsylvania and a member of the staff of the Population Studies Center there. He was graduated from Yale University with a B.A. in 1966. He went on to obtain his master's degree at Princeton University in 1971 and his doctorate from Carnegie-Mellon University in 1974. Since then he has been on the faculty at Pennsylvania.

CHARLES ELACHI ("Radar Images of the Earth from Space") is senior research scientist and team leader at the Jet Propulsion Laboratory of the California Institute of Technology. A native of Lebanon, he moved to France to begin his university education, getting his B.Sc. at the University of Grenoble and his Diplôme Ingénieur at the Institut Polytechnique in the same city. He came to the U.S. to do graduate work, earning his Ph.D. from Cal Tech in 1971. Since then he has been at the Jet Propulsion Laboratory, where he works on the theory of electromagnetism and the sensing of remote objects by means of radar. He was the senior worker in the group that built and employed the radar apparatus carried on the second and third flights of the space shuttle.

MARTHA CONSTANTINE-PATON and MARGARET I. LAW ("The Development of Maps and Stripes in the Brain") are neurobiologists who share an interest in the development of the visual system. Constantine-Paton is associate professor of biology at Princeton University. Her B.S. is from Tufts University and her Ph.D. from Cornell University. She writes: "I was trained initially as a sensory-system neurophysiologist, and I continue to maintain an active interest not only in vision but also in how the auditory and somatosensory systems process information. In fact, I became motivated to study sensory-system development because it seemed that the developmental and functional principles of neural organization might be similar and that a mechanistic understanding of how the brain is put together would help greatly in focusing research aimed at how the mature brain operates." Law has a bachelor's degree from Cornell. She earned her doctorate this year from Princeton for work she did in Constantine-Paton's laboratory on retinotectal specificity. She is now a fellow at the University of California at San Francisco Medical School, where, she writes, she is "examining some possible mechanisms by which the activity of visual pathways might determine their final connectivity patterns in newborn kittens."

HOO-MIN D. TOONG and AMAR GUPTA ("Personal Computers") are electrical engineers whose work centers on how computer systems and human organizations affect each other. Toong is assistant professor of management at the Sloan School of Management at the Massachusetts Institute of Technology and head of the digital-systems laboratory at the Center for Information Systems Research of M.I.T. His degrees in electrical engineering and computer science from M.I.T. include a B.S. (1967), an M.S. (1969) and a Ph.D. (1974). Gupta is a postdoctoral associate at M.I.T. His B.Tech. (1974) in electrical engineering and his Ph.D. in computer technology (1980) are from the Indian Institute of Technology in Kanpur. He has also received an S.M. from M.I.T. Since 1974 he has worked for the central government of India evaluating and purchasing computer systems. For the past four years he has divided his time between India and the U.S., doing work on computer systems.

RICHARD A. MEWALDT, EDWARD C. STONE and MARK E. WIEDENBECK ("Samples of the Milky Way") are astrophysicists who have worked together on the relative abundances of isotopes in cosmic rays. Mewaldt is senior research associate at the California Institute of Technology. He got his B.A. at Lawrence University in 1965 and went on to obtain his M.A. in 1967 and his Ph.D. in 1971 from Washington University. He moved to Cal Tech in 1971. He writes that he has employed data "from three NASA spacecraft... to investigate the isotopic and elemental composition of energetic nuclei accelerated by galactic sources, on the sun and in interplanetary space and to study energetic electrons from the sun and from Jupiter." Stone is professor of physics at Cal Tech. He went to that institution after receiving his master's degree (1959) and his doctorate in physics (1964) from the University of Chicago. His first work on cosmic rays was done in 1961 with the Discoverer satellites. He writes that since 1961 he has "investigated the isotopic and elemental composition of galactic cosmic rays and solar flare particles, studied planetary magnetospheres and the interplanetary medium, and coordinated the Voyager investigations of the outer solar system." Stone has served as principal investigator for six NASA spacecraft and is a recipient of the NASA Distinguished Service Medal. Wiedenbeck is assistant research physicist in the Space Science Laboratory at the University of California at Berkeley. His B.S. (1971) is from the University of Michigan; his Ph.D. (1978) is from Cal Tech. He went to Berkeley in 1978 and next year will go to the University of Chicago as assistant professor of physics and a member of the Enrico Fermi Institute.

M. A. R. KOEHL ("The Interaction of Moving Water and Sessile Organisms") is assistant professor of zoology at the University of California at Berkeley. She writes: "I started college as an art major but switched to biology when I discovered that exploring natural form using a scientific approach instead was more satisfying to me." After getting her B.A. at Gettysburg College in 1970 she went on to earn her Ph.D. in zoology from Duke University in 1976. After postdoctoral work at the University of Washington and the University of York in England she joined the faculty at Brown University. She moved to Berkeley in 1979.

CARL POMERANCE ("The Search for Prime Numbers") is professor of mathematics at the University of Georgia. He was an undergraduate at Brown University, from which he received his bachelor's degree in 1966. His graduate work was done at Harvard University; he got his M.A. in 1970 and his Ph.D. in 1972. In 1972 he went to Georgia and has remained there with the exception of a year spent at the University of Illinois at Urbana-Champaign. Pomerance's professional interests include number-theory algorithms, combinatorial number theory, multiplicative number theory and discrete geometry.

CLEO RICKMAN FITCH ("The Lamps of Cosa") is a student of architecture and art history. She studied art and architectural drafting and engineering drafting at George Peabody College for Teachers in Nashville. She went on to study art at the Watkins Institute and painting with the painter Charles Cagle. After moving to New York she studied at the Art Students League of New York for some years. Of her part in World War II she writes telegraphically: "War years. Worked in architect's office in Miami and for Army at Fort Oglethorpe, Ga., as draftsman making charts of engines, parts and systems for helping to train the enormous numbers of mechanics that were needed on the new equipment: jeeps, trucks, half-tracks, tanks." With her husband, the architect and architectural historian James Marston Fitch, she has designed and built houses and gardens. For the past 11 years she has studied art history at the American Academy in Rome. In the same period she has spent much time in Cosa, working on the subject of her article.

METAMAGICAL THEMAS

Sense makes more sense than nonsense, but nonsense may still have its purposes

by Douglas R. Hofstadter

Buz, quoth the blue fly,
  Hum, quoth the bee,
Buz and hum they cry,
  And so do we:
In his ear, in his nose,
  thus, do you see?
He ate the dormouse,
  else it was he.
—Ben Jonson

What does this mean? What is the point? Written in about 1600, this little nonsense poem begins with an image of insects, slides into an image of someone's face and concludes with an uncertain reference to the eater of a rodent. Although it makes little sense, it is still somehow enjoyable. It is comfortable and droll.

Nonsense has been around for a long time. Over the centuries, however, its style and tone have changed. The path of development of nonsense is interesting to trace. What marks something off as being nonsense? When does nonsense spill over into sense, or vice versa? Where are the borderlines between nonsense and poetry? These are issues to be explored in this column.

A century and a half after Jonson wrote his poem an English actor named Charles Macklin became notorious for boasting that he could memorize any passage on one hearing. To challenge Macklin a friend, the dramatist Samuel Foote, wrote the following odd passage:

So she went into the garden to cut a cabbage-leaf to make an apple-pie; and, at the same time, a great she-bear coming up the street pops its head into the shop—What! no soap? So he died; and she very imprudently married the barber: and there were present the Picninnies, and the Joblilies, and the Garyulies, and the great Panjandrum himself, with the little round button at top. And they all fell to playing the game of "catch as catch can," till the gunpowder ran out at the heels of their boots.

Full of non sequiturs and awkward, choppy sentences, this must have been an excellent challenge for Macklin. Unfortunately we have no record of how he fared on first hearing it, but we do know he enjoyed the passage immensely and went around reciting it with great gusto for years afterward.

In the 19th century the reigning monarchs of nonsense were Lewis Carroll and Edward Lear. Almost everyone knows Carroll's "Jabberwocky," "The Walrus and the Carpenter" and "Tweedledum and Tweedledee"; most people have heard of Lear's "The Owl and the Pussycat." Fewer have heard of Lear's "The Pobble Who Has No Toes" and "The Dong with the Luminous Nose." Carroll and Lear both enjoyed inventing strange words and using them as if they were commonplace. Their nonsense was expressed largely in poems, where they indulged in alliteration, internal rhymes, catchy rhythms and offbeat imagery. Rather than exhibiting works of those two authors, I have instead chosen, to represent their era, an anonymous poem with some of the same charming qualities, called "Indifference":

In loopy links the canker crawls,
Tads twiddle in their 'polian glee,
Yet sinks my heart as water falls.
The loon that laughs, the babe
  that bawls,
The wedding wear, the funeral palls,
Are neither here nor there to me.
Of life the mingled wine and brine
I sit and sip pipslipsily.

Many of Carroll's nonsense poems were parodies of popular songs or ditties of his day. Ironically, the parodies are remembered and most of the things that triggered them are forgotten. Carroll loved to poke fun, in his gentle way, at the stuffy mores and hypocritical mannerisms of society. One of the characteristics of "genteel" poetry of the 19th century was its precious use of classical literary allusions. Carroll seldom parodies this style, but Charles Battell Loomis, a little-known writer, admirably caught it in his "Classic Ode":

Oh, limpid stream of Tyrus, now I hear
The pulsing wings of Armageddon's
  host,
Clear as a colcothar and yet more
  clear—
(Twin orbs, like those of which the
  Parsees boast;)

Down in thy pebbled deeps in early
  spring
The dimpled naiads sport, as in the time
When Ocidelus with untiring wing
Drave teams of prancing tigers, 'mid
  the chime
Of all the bells of Phicol.

Scarcely one
Peristome veils its beauties now,
  but then—
Like nascent diamonds, sparkling
  in the sun,
Or sainfoin, circinate, or moss
  in marshy fen.

Loud as the blasts of Tubal, loud and
  strong,
Sweet as the songs of Sappho, aye
  more sweet;
Long as the spear of Arnon, twice as
  long,
What time he hurled it at King
  Pharaoh's feet.

This poem has the curious quality that when you read it, you think surely it must make sense and perhaps only another reading is needed. Then you read it again and find the same head-scratching feeling comes back to you. This is a problem with much modern poetry; it is hard to be certain you are not simply being taken for a ride by the poet, sucked in by some practical joker who has actually nothing in mind except tricking readers into thinking there is profound meaning where there is none.

The limerick is a form of poetry that is often featured in nonsense anthologies, probably because it is a playful form. Few limericks, however, make no sense. They may involve mild impossibilities, such as a young woman who travels faster than the speed of light or people who achieve more off-color feats, but in reality limericks are seldom nonsensical. One limerick that in its own way is pure nonsense is the following gem by W. S. Gilbert:

There was an old man of St. Bees,
Who was stung in the arm by a wasp.
  When asked, "Does it hurt?"
  He replied, "No, it doesn't—
I'm so glad it wasn't a hornet."

Why do I call this nonsense? Well, if it were a prose sentence, nothing about


A partridge in a pear tree
Two turtledoves
Three French hens
Four calling birds
Five gold rings
Six geese a-laying
Seven swans a-swimming
Eight maids a-milking
Nine ladies dancing
Ten lords a-leaping
Eleven pipers piping
Twelve drummers drumming

How Exxon
the mysteries

Scientists like John Sinfelt, Terry Baker and Dan Dwyer may one day enable us to design catalysts to order.

Catalysis has been a critical factor in the evolution of the petroleum industry. Catalytic conversion has made possible the majority of today's petroleum refining and synthetic fuels processes, as well as a large number of petrochemical processes. Our present understanding of the fundamental pathways of catalysis, however, is still extremely limited, largely due to past limitations in our analytical capability.

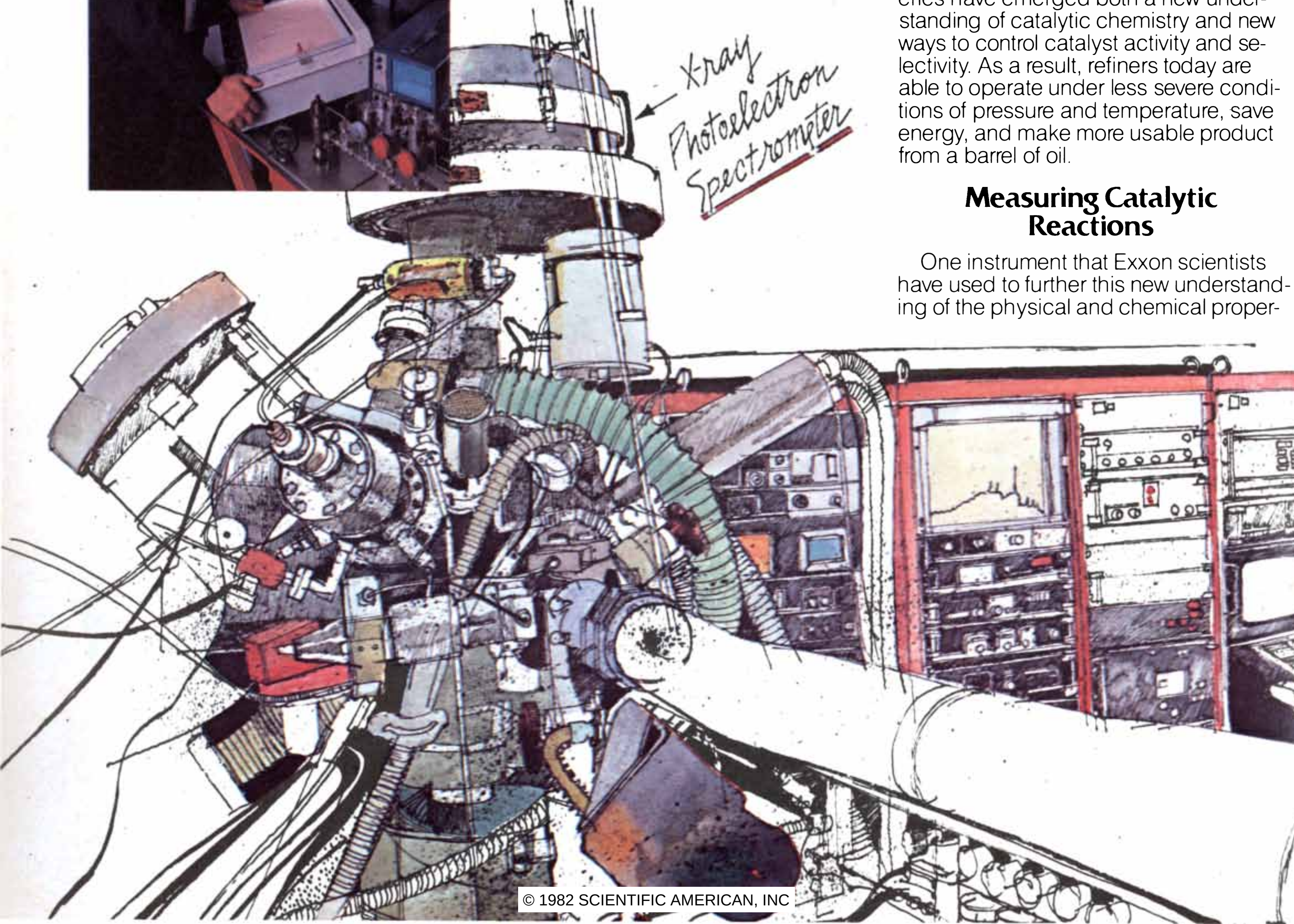
Traditionally, scientists evaluated a catalytic material simply by placing it in a reactor, admitting feed under suitable conditions of temperature and pressure, and examining the resultant products. This "black box" approach rendered it virtually impossible to link catalyst structure with reactivity. Hence, in years past the finding of a new catalyst owed more to art than to science. But today, scientists at Exxon are using advanced instrumentation with extraordinary capabilities to examine catalysts at work at the atomic level.

Fundamental Discoveries

In the mid-1960s, scientists at Exxon Research and Engineering Company (ER&E) made the fundamental discovery that supported bimetallic catalysts were vastly superior to supported single metallic catalysts. These catalysts, for example, have made it possible to produce high-octane gasoline without tetraethyl lead. Further research by ER&E led to the realization that all catalyst support materials modify to some extent the structure, electronic properties and chemical behavior of catalysts. From these discoveries have emerged both a new understanding of catalytic chemistry and new ways to control catalyst activity and selectivity. As a result, refiners today are able to operate under less severe conditions of pressure and temperature, save energy, and make more usable product from a barrel of oil.

Measuring Catalytic Reactions

One instrument that Exxon scientists have used to further this new understanding of the physical and chemical proper-



is solving of catalysis.

ties of catalysis is an x-ray photoelectron spectrometer coupled to a high-pressure catalytic reactor. Operating either under ultrahigh vacuum or pressure conditions, this novel device–one of only a handful in the world–not only measures the presence and strength of a metal support interaction, but also tests catalytic activity. Using a dedicated computer to analyze the tremendous amount of information generated in these reaction studies, researchers are unraveling the structure and reactivity of the catalytically active site.

Watching Catalysts at Work

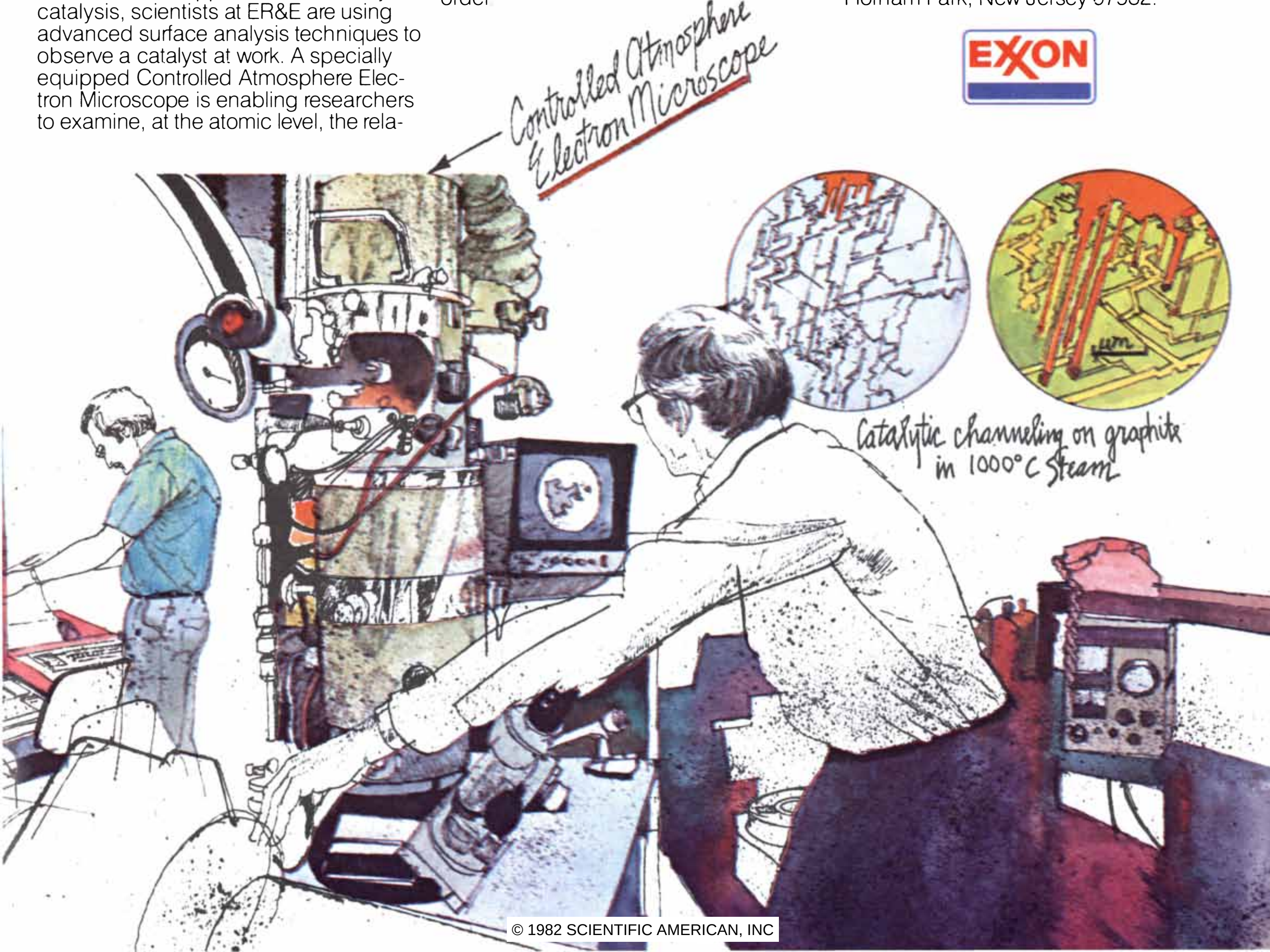
As a second approach to the study of catalysis, scientists at ER&E are using advanced surface analysis techniques to observe a catalyst at work. A specially equipped Controlled Atmosphere Electron Microscope is enabling researchers to examine, at the atomic level, the relationship between the structures of catalytic surfaces and the chemistries that occur there. This instrument, too, is one of only a few in the world, and the only one being used in private research. It has proved vital to our understanding of the kinetics and mechanisms of coal gasification.

Recognizing the importance of such *in situ* characterization, Exxon is further developing analytical instrumentation to probe both the catalyst and the reacting molecules while the catalytic reaction is in process. Using infrared, visible, ultraviolet and x-ray radiation, this sophisticated equipment could dramatically widen the horizons of catalysis, and one day enable us to design catalysts to order.

Exxon Research and Engineering Company

Catalysis is but one example of the research and engineering programs under way at Exxon Research and Engineering Company. A wholly owned subsidiary of Exxon Corporation, ER&E employs more than 2,000 scientists and engineers working on petroleum products and processing, synthetic fuels, pioneering science and the engineering required to develop and apply new technology in the manufacture of fuels and other products. For more information on catalysis or ER&E, write Ed David, President, Exxon Research & Engineering Company, Room 605, PO Box 101, Florham Park, New Jersey 07932.

EXXON



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it would attract much attention, except perhaps the name of the town. The nonsense is certainly not in the content but in the way it violates every standard set for the limerick form. It doesn't rhyme, its meter is a little bumpy and it has absolutely nothing funny in it—which is what makes it funny. And that is what makes it qualify as nonsense—in context.

Is nonsense always funny? Up until the 20th century it certainly seemed that way. In fact, nonsense and humor have traditionally been so closely allied that anthologies of nonsense appear to consist largely of humorous passages of any kind at all, regardless of how sensible they are. But nonsense and humor took widely divergent paths early in this century. Perhaps the greatest nonsense writer who ever lived was Gertrude Stein, although she is seldom mentioned in this connection. Entire collections of nonsense have been published without featuring a single piece of her work. Her most audacious effort in this genre is a volume of nearly 400 pages, modestly titled *How to Write.* Here is a sample of it, from a chapter called "Arthur a Grammar":

> Arthur a grammar.
> Questionnaire in question.
> What is a question.
> Twenty questions.
> A grammar is an astrakhan coat in black and other colors it is an obliging management of their requesting in indulgence made mainly as if in predicament as in occasion made plainly as if in serviceable does it shine.
> A question and answer.
> How do you like it.
> Grammar can be contained on account of their providing medaling in a ground of allowing with or without meant because which made coupled become blanketed with a candidly increased just as if in predicting example of which without meant and coupled inclined as much without meant to be thought as if it were as ably rested too. Considerable as it counted heavily in part.
> What is grammar when they make it round and round. As round as they are called.
> Did they guess whether they wished. A politely definitely detailed blame of when they go.
> What is a grammar ordinarily. A grammar is question and answer answer undoubted however how and about.
> What is Arthur a grammar.
> Arthur is a grammar.
> Arthur a grammar.
> What can there be in a difficulty.
> Seriously in grammar.
> Thinking that a little baby sigh can sigh.
> That is so much.
> Sayn can say only he is dead that he is interested in what is said.
> That is another in consequence.
> Better and flutter must and man can beam.
> Now think of seams.
> Embroidery consists in remembering that it is but what she meant.
> There an instance of grammar.
> Suppose embroidery is two and two. There can be reflected that it is as if it were having red about.
> This is an instance of having settled it.
> Grammar uses twenty in a predicament. Include hyacinths and mosses which grow in abundance.
> Grammar. In picking hyacinths quickly they suit admirably this makes grammar a preparation. Grammar unites parts and praises. In just this way.
> Grammar untiringly.
> Grammar perhaps grammar.

It is quite perplexing. It is simply an absurd string of non sequiturs, often totally lacking grammar, meandering randomly from "topic" to "topic." It is frustrating because there is nothing to grab on to. It is like trying to climb a mountain made of sand.

Stein's experiments in absurdity parallel the Dadaist and Surrealist movements of roughly the same period, and they mark the trend away from exuberant and laughable nonsense toward troubling and, later, macabre nonsense. Her work still has a freshness and silliness, however, that make it amusing and light rather than disturbing and heavy.

As we move further into the 20th century we encounter the philosophy of existentialism and the master expositor of existential malaise, Samuel Beckett. In Beckett's best-known play, *Waiting for Godot,* written in the early 1950's, the pathetic character ironically called Lucky has exactly one speech, coming in about the middle of the play. He has been taunted by the other characters with cries of "Think, pig!" and with sharp tugs on a rope around his neck, by which they are holding him. Eventually he is driven to the breaking point and pours out an incoherent, wild, tormented piece of absolute confusion, resembling regurgitated academic course work crossed with stock phrases and garbled memorized lists of one kind or another. Here is Lucky's celebrated speech:

> Given the existence as uttered forth in the public works of Puncher and Wattmann of a personal God quaquaquaqua with white beard quaquaquaqua outside time without extension who from the heights of divine apathia divine athambia divine aphasia loves us dearly with some exceptions for reasons unknown but time will tell and suffers like the divine Miranda with those who for reasons unknown but time will tell are plunged in torment plunged in fire whose fire flames if that continues and who can doubt it will fire the firmament that is to say blast hell to heaven so blue still and calm so calm with a calm which even though intermittent is better than nothing but not so fast and considering what is more that as a result of the labors left unfinished crowned by the Acacacacademy of Anthropopopometry of Essy-in-Possy of Testew and Cunard it is established beyond all doubt all other doubt than that which clings to the labors of men that as a result of the labors unfinished of Testew and Cunard it is established as hereinafter but not so fast for reasons unknown that as a result of the public works of Puncher and Wattmann it is established beyond all doubt that in view of the labors of Fartov and Belcher left unfinished for reasons unknown of Testew and Cunard left unfinished it is established what many deny that man in Possy of Testew and Cunard that man in Essy that man in short that man in brief in spite of the strides of alimentation and defecation wastes and pines wastes and pines and concurrently simultaneously what is more for reasons unknown in spite of the strides of physical culture the practice of sports such as tennis football running cycling swimming flying floating riding gliding conating camogie skating tennis of all kinds dying flying sports of all sorts autumn summer winter winter tennis of all kinds hockey of all sorts penicilline and succedanea in a word I resume flying gliding golf over nine and eighteen holes tennis of all sorts in a word for reasons unknown in Feckham Peckham Fulham Clapham namely concurrently simultaneusly what is more for reasons unknown but time will tell fades away I resume Fulham Clapham in a word the dead loss per head since the death of Bishop Berkeley being to the tune of one inch four ounce per head approximately by and large more or less to the nearest decimal good measure round figures stark naked in the stockinged feet in Connemara in a word for reasons unknown no matter what matter the facts are there and considering what is more much more grave that in the light of the labors lost of Steinweg and Peterman it appears what is more much more grave that in the light the light the light of the labors lost of Steinweg and Peterman that in the plains in the mountains by the seas by the rivers running water running fire the air is the same and then the earth namely the air and then the earth in the great cold the great dark the air and the earth abode of stones in the great cold alas alas in the year of their Lord six hundred and something the air the earth the sea the earth abode of stones in the great deeps the great cold on sea on land and in the air I resume for reasons un-


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known in spite of the tennis the facts are there but time will tell I resume alas alas on on in short in fine on on abode of stones who can doubt it I resume but not so fast I resume the skull fading fading fading and concurrently simultaneously what is more for reasons unknown in spite of the tennis on on the beard the flames the tears the stones so blue so calm alas alas on on the skull the skull the skull the skull in Connemara in spite of the tennis the labors abandoned left unfinished graver still abode of stones in a word I resume alas alas abandoned unfinished the skull the skull in Connemara in spite of the tennis the skull alas the stones Cunard tennis . . ∴ the stones . . . so calm . . . Cunard . . . unfinished. . . .

At about the same time as Beckett was writing this play, or perhaps a few years earlier, the Welsh poet Dylan Thomas, intoxicated with the sounds of the English language, was creating poems that are remarkably opaque. Consider the opening two stanzas (there are five altogether) of his Poem "How Soon the Servant Sun":

How soon the servant sun,
(Sir morrow mark),
Can time unriddle, and the cupboard
  stone,
(Fog has a bone
He'll trumpet into meat),
Unshelve that all my gristles have a
  gown
And the naked egg stand straight,

Sir morrow at his sponge,
(The wound records),
The nurse of giants by the cut sea
  basin,
(Fog by his spring
Soaks up the sewing tides),
Tells you and you, my masters, as
  his strange
Man morrow blows through food.

Poems such as this make me want to cry out that the emperor has no clothes. As far as I can discern, close to no meaning can be pulled from these lines. But can I be sure? I cannot. All I can say is that it would probably take such a great effort to "decode" these lines that I suspect very, very few people would be willing to make it.

It is perhaps not so well known that the American singer Bob Dylan (whose name was taken from Dylan Thomas) is also an author of inspired nonsense. Some of his nonsense written in the 1960's was collected and published in a book called *Tarantula*. Its tone is often bitter and it exudes the confused mood of those difficult years. Most of the pieces in the book consist of an outburst of free associations followed by a letter from some strangely named personage or other. The following sample is called "On Busting the Sound Barrier":

The neon dobro's F hole twang & climax from disappointing lyrics of upstreet outlaw mattress while pawing visiting trophies & prop up drifter with the bag on head in bed with next of kin to the naked shade—a tattletale heart & wolf of silver drizzle inevitable threatening a womb with the opening of rusty puddle, bottomless, a rude awakening & gone frozen with dreams of birthday fog/ in a boxspring of sadly without candle sitting & depending on a blemished guide, you do not feel so gross important/ success, her nostrils whimper. the elder fables & slain kings & inhale manners of furious proportion, exhale them against a glassy mud . . . to dread misery of watery bandwagons, grotesque & vomiting into the flowers of additional help to future treason & telling horrid stories of yesterday's influence/ may these voices join with agony & the bells & melt their thousand sonnets now . . . while the moth ball woman, white, so sweet, shrinks on her radiator, far away & watches in with her telescope/ you will sit sick with coldness & in an unenchanted closet . . . being relieved only by your dark jamaican friend—you will draw a mouth on the lightbulb so it can laugh more freely

forget about where youre bound.
youre bound for a three octave
fantastic hexagram. you'll see
it. dont worry. you are Not bound
to pick wildwood flowers . . . like
i said, youre bound for a three
octave titanic tantagram
your little squirrel,
Pety, the Wheatstraw

Dylan is not the only popular singer of the 1960's to have had something of a literary bent. John Lennon, when he was in his early twenties, reveled in the nonsensical and published two short books called *In His Own Write* and *A Spaniard in the Works*. They are still available, bound together in a single paperback volume. Two of Lennon's poems will serve to illustrate his idiosyncratic style.

I Sat Belonely

I sat belonely down a tree,
humbled fat and small.
A little lady sing to me
I couldn't see at all.

I'm looking up and at the sky,
to find such wondrous voice.
Puzzly puzzle, wonder why,
I hear but have no choice.

"Speak up, come forth, you ravel me,"
I potty menthol shout.
"I know you hiddy by this tree."
But still she won't come out.

Such softly singing lulled me sleep,
an hour or two or so
I wakeny slow and took a peep
and still no lady show.

Then suddy on a little twig
I thought I see a sight,
A tiny little tiny pig,
that sing with all its might.

"I thought you were a lady,"
I giggle,—well I may,
To my suprise the lady
got up—and flew away.

The Faulty Bagnose

Softly softly, treads the Mungle
Thinner thorn behaviour street.
Whorg canteell whorth bee asbin?
Cam we so all complete,
With all our faulty bagnose?

The Mungle pilgriffs far awoy
Religeorge too thee worled.
Sam fells on the waysock-side
And somforbe on a gurled,
With all her faulty bagnose!

Our Mungle speaks tonife at eight
He tell us wop to doo
And bless us cotten sods again
Oamnipple to our jew
(With all their faulty bagnose).

Bless our gurlished wramfeed
Me curséd café kname
And bless thee loaf he eating
With he golden teeth aflame
Give us OUR faulty bagnose!

Good Mungle blaith our meathalls
Woof mebble morn so green the wheel
Staggaboon undie some grapeload
To get a little feel
of my own faulty bagnose.

Its not OUR faulty bagnose now
Full lust and dirty hand
Whitehall the treble Mungle speak
We might as wealth be band
Including your faulty bagnose.

Give us thisbe our daily tit
Good Mungle on yer travelled
A goat of many coloureds
Wiberneth all beneath unravelled
And not so MUCH OF YER FAULTY
  BAGNOSE!

The first of these is transparent and charming; the second is baffling and disturbing. What in the world is a bagnose? No clear image comes through. And why are all these bagnoses faulty? And does "faulty" have its normal meaning here? It is hard to tell.

The idea of "normal meanings" is


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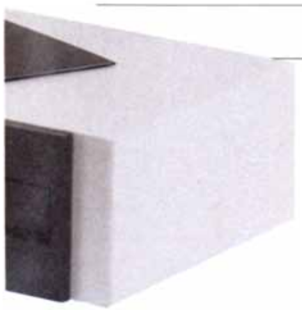

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stood on its head in a recent book of poetry by William Benton called just that: *Normal Meanings.* One section of the book is titled "Normal Meanings"; here is an extract from it:

Escape is, escape
was, once more,

continued.

Vineyards
as dusky.

He watches it wrinkle into a school bell.

It isn't music sometimes, I'm
happy.

Leaves, practically falling
off and into the air.

Hills river

sunset ice-cream

cone.

The buildings. Things
build up. It
must be so many
normal meanings.

The downstairs lights. Probably I doubt.

These and other

stories.
The loveliness
of houses.

Clarissa is the name of the bug I
just sent somewhere.

The falseness it abjures has seemed in
statements we are losing.
It's hard to say. A note of privilege
which turns up here in their appearances.
I drink.

The cobweb is becoming a strand of
lamplight, its black heart

blessed.

A nice
Elaine
by the beer.

Some may find the amorphousness of this type of poetry amusing or engaging; others may find it tiresome and confusing. I personally find it provocative for a while, but then I begin to lose interest.

I have somewhat greater interest in the writings of a little-known rhetorician named Y. Serm Clacoxia, who in the past 25 years or so has penned sporadically various pieces of nonsense poetry and prose. Clacoxia's prose is marked by a certain degree of vehemence and fire, although it is sometimes a little hard to figure out exactly what he is ranting about. Here follows one of his tracts, titled "The Illusions of Alacrity":

For millennia it has been less than appreciated how futile are the efforts of those who seek to sow sobriety in the furrows of trivia. To those of us who have striven to clarify what has been left unclear, it has proven a loss. To others who, whilst valiantly straddling the fine line that divides arid piquancy from acrid pungency, have struggled to set right the many Undeeds and Unsaids of yore, life has shown itself as a beast of many colors, a mountain of many flags, a hole of many anchors.

Who, in fact, were the Outcasts of Episode, if not the champions of clarity? Where, indeed, were the witnesses to litany, when their fortress of fecundity was a-being stormed by the Ovaltine Monster, that incubus of frozen cheerios and swollen bananas? And dare one wonder, with the bassoon of lunacy so shrilly betoning the ruined fiddles of flatulism, how it is that doublethink, narcolepsy, and poseurism are unthreading themselves across our land like tall, statuesque, half-uneaten yet virtuous whippoorwhills? Can it be that a cornflake-catechism has beguiled us into an unsworn acceptance of never-takism?

What sort of entiments are they, that would uncouch a mulebound lout and churlishly swirl his burly figure, unfurl and twirl his curly figure, hurl his whirly figure, into the circuline vaults of hysteresis? With a drop of sweat unroasting his feverish brow, we decry his fate; with the patience of a juggernaut and the telemachy of a dozen opossums, we lament his disparity. And summoning all the powers that be, we unbow the jelly of our broken dreams, dashing it with the full fury of a pleistocene hurdy-gurdy against the lubrified and bulbous nexus of that which, having doomed the dinosaurs, seeks the engulfing of all that moves.

Thus we act; and perhaps action itself is the Anatole's Curlicue of our era. It is high time to recognize that action, and action alone, will be the agent that transmutes the flowery barrier of unutterability into an arbitrary but sacred iota of purposefulness, which cannot help but penetrate into an otherwise nameless and universally spaghettified lack of meaning, which smears and beclouds the crab-lit hopes of half-beings begging for deliverance from their own private, yet strangely tuberculine maelstroms that begat, and begotten were from, a howling sea of ribosomal plagiarism.

This is deliberate nonsense, of course, to be contrasted with the nondeliberate nonsense of, say, Dylan Thomas. Another vein of nondeliberate nonsense is crackpot ideas in science. Such ideas seem to be an inevitable ingredient of any society in which serious scientific research is carried out; there is no way to plug all the cracks, so to speak. There is no way to ensure that only high-quality science will be done. Fortunately most journals do not publish absolute nonsense or gobbledygook; it is filtered out at an early stage. There is one journal I have come across, however, whose pages are filled with utter nonsense—meant seriously. It is called *Art-Language.* To show what I mean, here is a short excerpt from the May 1975 issue, taken from the beginning of an article called "Community Work." It seems from the table of contents to have been written by three people collectively.

Dionysus gets a job. (Re: language has got a hold on U.S.) (It's a Whorfian conspiracy!)

This is hopeless manqué ontological alienation which is still dealing with ideas about "discovery" as a function of a metaphysics of categories. Only for researchers is the failure of the modal logic industry to "catch-my-experience"—the birth of tragedy.

Going-on in AL [*Art-Language*] indexed (somehow) is a thing-in-and-for-(dynamically)-itself. That we never catch up with the NaturKulturLogik has little to do with the "actualizing" sets of the frozen dialogue... and it's not just a ledger; our problems with set theoretical axiomata are embedded into our praxis as more than just historical antecedents... more than nomological permissibility... more than selective filtration. We still don't recognize ourselves as very fundamental history producers.

The possibility of a defence of a set, as with "a decision," is an index-margin of a prima facie ersatz principle for action (!). (There is no workable distinction between oratio recta and oratio obliqua.) All we are left with is a deontic Drang. Think of that as a chain strength possibility of what, eventually, comes out as a product (epistemic conditions?) and the product is not a Frankfurt-ish packing-it-all-in.

I am tempted to quote more, to show how the wild quality of the prose persists without letup, but life is short. It is hard to believe this was meant to communicate something to anyone, but the journal appears regularly (at least it used to) and can be found on the shelves of reputable art libraries. The curious thing abqut *Art-Language* is that the collective that writes it appears to consist of people who are concerned with issues of much interest to me: the nature of reference, the relation of wholes to parts, the connection of art and reality, the philosophy of set theory and the questionable existence of mathematical concepts, the structure of society and so on. What is amazing is how such concepts can be so obscured by language that it is hard to make out anything except a lot of smoke.

An American poet whose work explores ground halfway between nonsense and sense is Russell Edson. He writes tiny surrealistic vignettes that shed a strange light on life. Often he executes strange reversals, as of animate and inanimate beings, or human beings and animals. His grammar is also oblique, one of his favorite devices being to refer repeatedly to something specific with the indefinite article "a," thus disorienting a reader. A typical sample of Edson's style is the following, drawn from his book *The Clam Theater:*

When Science Is in the Country

When science is in the country a cow meows and the moon jumps from limb to limb through the trees like a silver ape.

The cow bow-wows to hear all voice of itself. The grass sinks back into the earth looking for its mother.

A farmer dreamed he harvested the universe, and had a barn full of stars, and a herd of clouds fenced in the pasture.

The farmer awoke to something screaming in the kitchen, which he identified as the farmerette.

Oh my my, cried the farmer, what is to become of what became?

It's a good piece of bread and a bad farmer man, she cried.

Oh the devil take the monotony of the field, he screamed.

Which grows your eating thing, she wailed.

Which is the hell with me too, he screamed.

And the farmerette? she screamed.

And the farmerette, he howled.

A scientist looked through his magnifying glass in the neighborhood.

This eerie tale leaves one with a host of unresolved images. That, of course, is Edson's intent. And in this regard Edson's work is quite typical. Most of the nonsense of the 20th century, it seems, has this deliberately upsetting quality to it, reflecting a deep malaise. It is quite different from the nonsense of the preceding centuries.

Perhaps one of the virtues of nonsense is that it opens our minds to new possibilities. The mere juxtaposition of a few arbitrary words can send the mind soaring into imaginary worlds. It is as if sense were too mundane and we needed a breather once in a while. Perhaps sense is also too confining. Nonsense stresses the incomprehensible face of the universe; sense stresses the comprehensible. Clearly both are important. Zen teachings have striven to impart the path to "enlightenment." Although I do not believe such a mystical state exists, I am fascinated by the paths that are offered. Zen itself is perhaps the archetypal source of utter nonsense. It seems fitting to close this column with two Zen koans taken from the "Mumonkan," a set of koans commented on by the Zen master Mumon in the 13th century.

Joshu Examines a Monk in Meditation

Joshu went to a place where a monk had retired to meditate and asked him: "What is, is what?" The monk raised his fist. Joshu replied: "Ships cannot remain where the water is too shallow." And he left. A few days later Joshu went again to visit the monk and asked the same question. The monk answered the same way. Joshu said: "Well given, well taken, well killed, well saved." And he bowed to the monk.

Mumon's comment: The raised fist was the same both times. Why is it Joshu did not admit the first and approved the second one? Where is the fault? Whoever answers this knows that Joshu's tongue has no bone so he can use it freely. Yet perhaps Joshu is wrong. Or, through that monk, he may have discovered his mistake. If anyone thinks that the one's insight exceeds the other's, he has no eyes.

Mumon's poem:

The light of the eyes is as a comet,
And Zen's activity is as lightning.
The sword that kills the man
Is the sword that saves the man.

Learning Is Not the Path

Nansen said: "Mind is not Buddha. Learning is not the path."

Mumon's comment: Nansen was getting old and forgot to be ashamed. He spoke out with bad breath and exposed the scandal of his own home. However, there are few who appreciate his kindness.

Mumon's poem:

When the sky is clear the sun appears,
When the earth is parched rain will fall.
He opened his heart fully and spoke out,
But it was useless to talk to pigs and
fish.

BOOKS

A Christmas survey of books about science for children young and old

by Philip and Phylis Morrison

We report this year on a group of books of high quality. This time it was apparent the good old tradition that most titles deal with nature and living things is beginning to shift. More and more books appear that seem to treat of technology, very broadly seen. Through technology the authors reach some of the more abstract material we would regard formally as physical science.

Dinosaurs and Before

SUPERSAURUS, by Francine Jacobs. Pictures by D. D. Tyler. G. P. Putnam's Sons ($6.99). DINOSAURS OF NORTH AMERICA, by Helen Roney Sattler. Illustrated by Anthony Rao. Lothrop, Lee & Shepard Books ($10.95). DINOSAURS, by L. B. Halstead. Illustrated by Jenny Halstead. Blandford Press, distributed by Sterling Publishing Co., Inc., New York, N.Y. ($10.39). DINOSAURS IN YOUR BACKYARD, written and illustrated by William Mannetti. Atheneum ($10.95). The dinosaur lives, and each current excitement among the vertebrate paleontologists resonates loudly along the bookshelves. No fewer than four excellent and diverse books will stand here for a still larger number of worthy new volumes.

Supersaurus is meant for the youngest of readers: 60 words of text fill a page. The book celebrates a real hero; there he stands, robust, hard-hatted, gloved hand on the shovel. His catch stands taller than he does: the seven-foot shoulder blade of a "gentle giant," the biggest dinosaur ever found. We watch the find as Dinosaur Jim first cleverly uncovers a half-buried hipbone and then comes back to ponder the marvel by moonlight. The neck bone nearby was as big as a teacher's desk, drawn here to show it. Reconstructed, the beast must have been an adult of some 70 tons, browsing happily on the high tree ferns of its time, half a ton of greens and more per day.

The pictures show the imagined swampy past along with the present: a dry, piny Colorado valley winding past the cliffs where the bones were found in 1972. All these textured pictures are wonderfully winning, paleontologist, sauropod and canyon alike, not to mention the "supersaurus," shown balanced on a great pair of scales against 14 circus elephants. It is all true, too. James A. Jensen, a field paleontologist, is director of the museum at Brigham Young University in Provo, Utah, where the kids gave him his digger's name. The 16-ton dinosaur skeleton has not yet been assembled, nor has it earned a formal name for itself. But how much Dinosaur Jim deserves his own epithet is demonstrated by the remarkable fact that in 1979 he found at the same site yet another shoulder bone, this one *nine* feet tall; "for now, he is calling this new discovery ULTRASAURUS."

The other three books convey an exciting and novel narrative, broadly in agreement. Each of them rests the tale on a parade of wonderful forms. The books differ strongly, however, in level and purpose. Both *Dinosaurs of North America* and *Dinosaurs* are chronicles, the animals arranged in rough time sequence, a description of fossil finds with comment on the living animal for each species illustrated. The first of those two books is limited to the wide range of North American forms.

Rao's deft wash monochromes reconstruct the animals, many of them in full-spread figures against their landscapes. The text offers background information, from simple maps of the old fused continents to a fine summary of conjectures about extinction, all at the level of a dinosaur-savvy reader in the upper grades. It is brief and not very technical. The Halstead illustrations are instead a display of a hundred restorations worldwide, all shown as hard-edged color images on a white ground, very like the seashells or even the aircraft of many other pictorial compendiums. The Halsteads are a team out of the world of science; their text is tightly packed, more technical and distinctly up-to-date, with much new material from China and Mongolia. They aim at a book of reference, a field guide, as it were.

Dinosaurs in Your Backyard is strikingly original, the work of a devoted amateur, himself trained as an artist. Although he treats specific animals, using a variety of drawings and diagrams, the text is in fact a careful, connected argument. Its burden is the new understanding of the past, and its engrossing method is a list of points for and against each of the older views, a sharp eye on error, ambiguity, uncertainty. It is a striking exercise in probable inference for young readers willing to think and to doubt.

The new story is remarkable, although it is plainly still unsettled; no consensus has been reached. Dinosaurs have not vanished without issue; the birds in your backyard seem to have arisen from the lineage of the celurosaurids: speedy, lightly built, clawed biped-al predators. The big herbivores, the thunder lizards, were not cold-blooded aquatic monsters, sluggish and stupid. They may or may not have been semi-aquatic, but on land they moved in herds, raising the possibility that the young were born alive; it is hard to see how a tiny hatchling could have kept up. They were warm-cored animals, a state assured by their huge bulk.

Carnivores did indeed prey on the herds. That, however, was not the role of *Tyrannosaurus,* the favored dragon surrogate of film and cartoon. Its great teeth and huge jaws tore at meat, all right, but mainly at carrion. They were not strong enough for combat, and the giant meat seekers waddled too slowly on hind legs, tail out horizontal, to catch the herds. The most feared carnivores were probably the fast, birdlike two-legged hunters such as *Deinonychus,* with a bone-stiffened tail able to move only up and down as a balancing aid. They were the size of today's ferocious spotted hyenas, and like them they may have hunted in packs; one fossil find held five of the hunters along with one herbivore the weight of half a dozen predators. Young tyrannosaurs may have been able to take living prey, particularly a straggling calf, but the role of true Mesozoic tiger has not yet been cast.

Mannetti offers the best metaphor for the current state of affairs. We know that the depths of the past held a wondrous set of monsters; so much is certain. When it comes to the details, however, we have much to learn; we make our dinosaurs over in each generation. With each blow of the paleontologist's chisel, each new understanding of the subtle engineering of an animal and its niche, "the future keeps chipping away at the past."

The Russian paleontologist A. G. Sharov has found a winged gliding pterosaur fossil with impressions of soft, fleecy fur. Those gliders ruled the calm air of dinosaur days; only the smaller of them flapped like bats. They were warm-blooded; some caught insects, others fish. If the newly found Texas example really was 50 feet in wingspan, it was the largest of all fliers before our

own species took to the air with graphite bone and polyamide skin.

EARLY LIFE, by Lynn Margulis. Science Books International, Inc., Boston, Mass. ($16.50). Courbet's delicate, dreamy painting of a flat, still and "time-forgotten seashore" spreads across the dust jacket of this fresh small excursion to the hidden frontiers of paleontology. Although personal and clearly written, the text is not easy, but it quickly draws any reader with a high school preparation in biology (and a touch of chemistry) into the deepest biological past. That past was all microbial: life stayed close to the wet flats for two billion, perhaps even three billion, years of evolution. In that time single cells "invented nearly everything in the modern repertoire of life except, perhaps, language and war."

No one with a sense of evidence will resist the strong inference from one photograph, where the reader sees a cut exposed in a dolomite cliff along the Aldan River in Siberia. The limy rocks there rise stratum by stratum the height of a big house. The layers of rock all look the same; there is no visible change along this section of a shallow marine world of the ancient Cambrian. Yet above a certain layer there is found a rich fossil fauna, with more than 60 species of animals, all having hardened skeletal parts. Below that layer no such specimens exist; a few traces of soft-bodied animals are to be found, along with the fossil microbial mats called stromatolites. The showy trilobites of the Cambrian, with the relics of all the bony ages of the half billion years that followed it, crowd our museums, but that sudden change was not in air, sea or rock; it was in life itself. Before that time life was rich but tiny, with no hard parts; afterward it was shells, bones and teeth, along with the microscopic lowly.

The chapters begin with the distinction between the bacterial and the larger nucleated cells, then tell of cellular life first without and then with free oxygen and go on to treat the specialized organelles by which cells of all higher forms make fuel, move and choreograph the strict dance of genetic partition that underlies sex. Professor Margulis argues for the origin of those little organelles out of ancient partnerships struck between simpler cells in the past, although she deals fairly with the still uncertain issues of her attractive scheme. Here too is the drama of the origin of free oxygen, the greatest impact of life on the global environment, well begun perhaps two billion years ago by those minute but abundant photochemists, the cyanobacteria. You see a fine section of the mysterious and widespread banded iron-rich cherts to mull over. A glossary helps to deal with all the jargon needed to name and describe the life forms of such a varied and unfamiliar garden-zoo. The drawings that head the chapters are enough to entice any reader with a fondness for past and present forms of life along the wilder paths of microbiology. A bacterial form not unlike a prickly pear 100 microns high? It is here, along with an animal a few times larger that is only a bag of ciliated cells.

More Living Things

NATURE'S CLEAN-UP CREW: THE BURYING BEETLES, by Lorus J. Milne and Margery Milne. With photographs by the authors and drawings by Tom Prentiss. Dodd, Mead & Company ($7.95). On the authority of Shakespeare, gravediggers, at least in old Denmark, have a ready wit. It turns out that burying, or sexton, beetles show behavior so apt, versatile and caring that it seemed incredible for a long time after the first studies, which were reported a century back by Jean Henri Fabre in his "peasant's simple way." Today there is no doubt: these authors have the photographs and even a film to prove it.

On a midsummer day any small dead bird or mammal in open country, even a city garden, is likely to attract a burying beetle within half an hour. The faintest odor of decay is a sure signal. A dead groundhog or house cat is too big, a sparrow or a mouse just right. The beetle arrives, in our country one of a hundred species worldwide. (There are no burying beetles in Australia or in sub-Saharan Africa.) Time presses. At once the beetle sets about the task, laboriously inching the heavy burden to soft soil by tunneling under it repeatedly, to urge it forward from below with his legs. A mouse corpse moves a yard in a couple of hours. Soon a second beetle will join the first; the pace quickens. In the nearest soft soil a loosened grave is prepared in the intervals of the halting cortege. Every blade of grass is an obstacle, but the beetles somehow bend the blade or push aside a small piece of gravel with the moving body.

The two cooperate; they work like "six-legged bulldozers," because by dawn they must bury the find, safe from the attention of flies and ants. A few hours more and their load sinks into the soft grave pit. They have been seen to bury an entire mousetrap with the dead mouse in it, or to cut a string that prevented a corpse from falling to the ground; they saw, shake, bend, lift. Once within the crypt the pair may mate, and soon enough a dozen or so small eggs appear. The dead body will nourish the larvae to the pupal stage. The parents remain in the grave, removing hair or feathers, pushing the treasure into a ball, somehow "embalming" it against decay. Mother and father alike feed the young as though the larvae were fledglings in the nest. When the young pupate, the parents leave by an escape tunnel they provide for the emergence of their offspring.

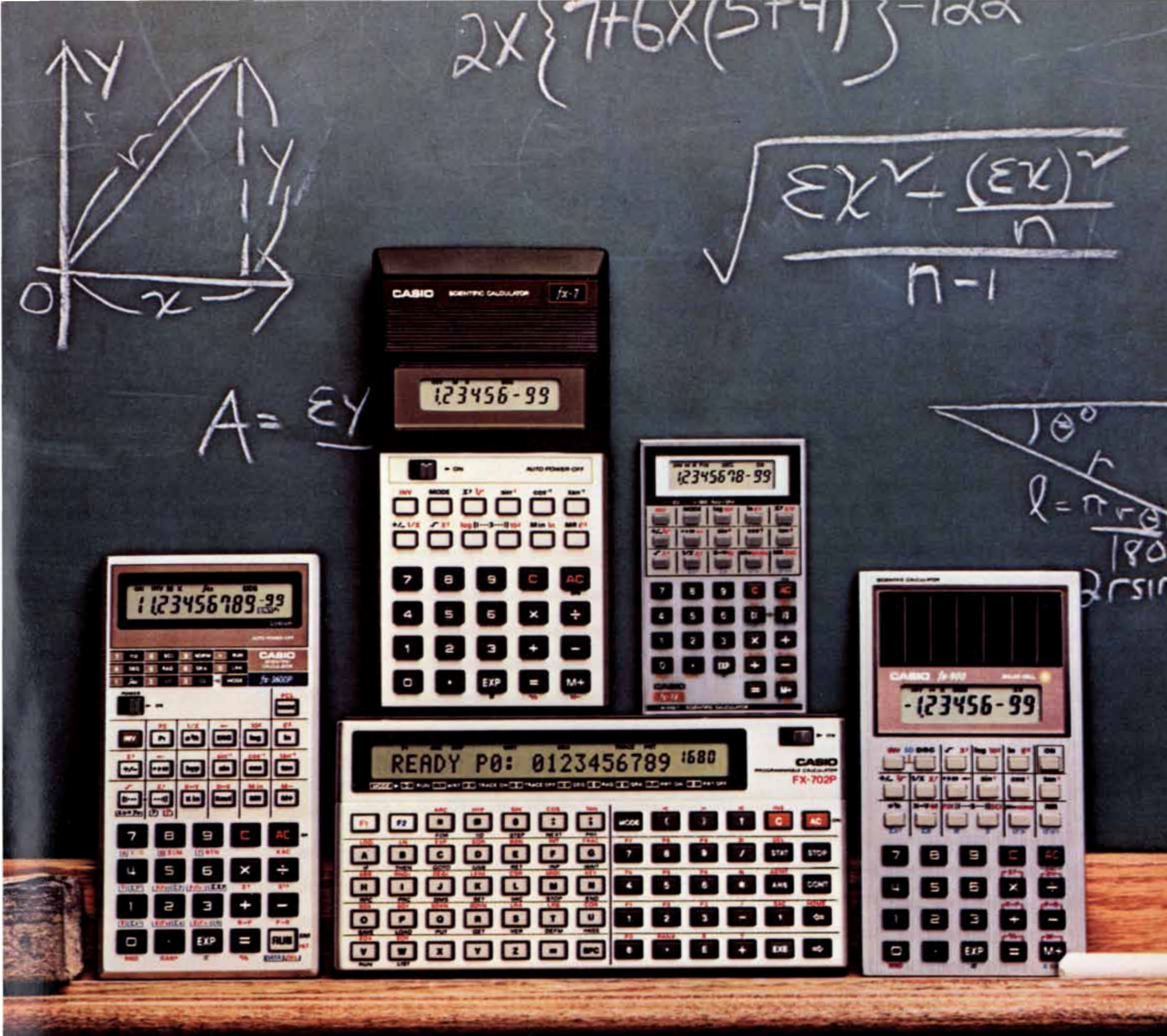
Enough; the Milnes tell just how to lure burying beetles and to study their deeds. Some species are still found widely in the U.S., although the giant kind that once buried dead fish cast up on Atlantic beaches is all but extinct. There are too many gulls there now, with municipal grants of garbage, and in city and suburb there are getting to be too many raccoons and skunks. Big scavengers are tough competitors for the beetles. The novelty and clarity of this volume based on first-hand research make it an outstanding example for grade school naturalists. Someday the subtle program of the beetles will be clear.

SILKWORMS, by Sylvia A. Johnson. Photographs in color by Isao Kishida. Adapted from the Japanese of Isao Kishida, as translated by Chaim Uri. Lerner Publications Company, Minneapolis, Minn. ($8.95). FUZZ DOES IT! by Vicki Cobb. Illustrated by Brian Schatell. J. B. Lippincott ($10.50). For two days straight the silkworm moves its head to and fro about once per second in figure eights a few millimeters at a swing. By that time it has spun out a full mile of the fine double-fused fiber of strong silk, layer on layer of figure eights by the hundred thousand from the outside of the cocoon inward. It has molted four times to reach this stage, the size of a finger, a fourth of its weight occupied by the silk glands. There had hatched from the golden egg less than a month earlier a tiny dark grub smaller than a grain of rice. Mulberry leaves are the nutrient; patient breeders have over many centuries selected a domestic animal, more of an artifice than a dachshund or a Chihuahua. Silkworms are almost too weak to walk to feed; they are placed among freshly chopped rich green leaves. The few chosen for adulthood become moths with large bodies and dwarfed wings; they need not fly to find a mate.

This small book with its dramatic and detailed color photographs of silkworm culture at every stage is a remarkable study of insect metamorphosis. It will be admired and enjoyed by any young person who has ever seen that transformation or wondered about it.

The second book, with its amiable kid's title, is an original, straddling a frontier between materials science and natural history. It is based on the use of a hand magnifier, for which it offers a genuine research program, beginning with fuzz on your arm or on a mitten and passing on to a dandelion, a spiderweb, the fibers of a fresh pineapple leaf, making paper from the lint trapped in a clothes dryer and the easy hand spinning of a small sample of lamb's wool.

The theme is fibers and their aggre-



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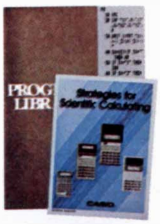

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Honeywell

Although Honeywell engineering is world-wide, the bulk of research and applied research is done in Minneapolis. The most recent Quality of Life Study conducted by Midwest Research Institute shows Minnesota to be one of the best places in the country to live and work considering cultural, social, economic, educational and political factors.

This ideal research environment is further enhanced by Honeywell's affiliations with universities. We have an ongoing program of seminars with Berkeley, MIT, Stanford, the University of Kiel, the University of Illinois, Cornell, Purdue and the University of Minnesota.

gates: random in dust, variously ordered in artifacts and in organisms. The experiences suggested are workable and fun; they amount to a serious connected investigation for small children. (Only the first experiment, on keeping a can filled with hot water warm by wrapping it with a wool sock, is inconclusive; there are too many variables. The result is clear to many small northerly experimenters anyway from their wool mittens.) Even the microscopic world is brought close at the end of the book, where drawings compare 20- or 30-power views of household fibers.

FROST HOLLOWS AND OTHER MICROCLIMATES, by Laurence Pringle. William Morrow and Company ($6.95). VAMPIRE BATS, by Laurence Pringle. William Morrow and Company ($7.50). The ocean beach in summertime has a familiar microclimate. By day the cool breeze blows in from the sea, as many a grade school ecologist knows. At night the flow reverses. Here the physics is pretty clear: by day hot air rises warmed by that sun-beaten surface hot enough to burn an unwary foot; by night the thin sand layer quickly cools while the ocean holds its heat. Dark rocks may melt fresh snow; the weather on a southern slope is quite different from that on the cool, shady north face of the same valley. There is a frost hollow in the Austrian Alps about 500 feet deep into a plateau; it is a record breaker, with freezing temperatures often found in the hollow in midsummer as cool air flows downhill into it each night.

In forest and desert such local effects, large and small, shape the strategies of plant and animal. Human beings too exploit these local facts of real life. The igloo and the saltbox are formed to fend off the northern cold and hold expensively warmed air stably in upper living quarters. The gardener's hot caps protect young melon plants by night. Design that ignores such features is wasteful, as many an air-conditioned glass-walled tower bears expensive witness.

Frost Hollows is a straightforward, thought-inducing introduction to its topic and a concise piece of inductive science for observant youngsters in the primary grades. *Vampire Bats,* by the same admirably versatile writer, is quite another story. Its form is similar; you can learn a lot from the words and the invariably apt photographs. One shows Bela Lugosi as Count Dracula in full fig. The rest of the book treats the life of real vampires, bats no larger than your hand that range today from Uruguay to Yucatán, a threat to cattle raisers of the region because of the rabies they carry. Vampire populations can nowadays be controlled by clever means, without the slaughter of all the bats or the dynamiting of caves and trees. Vampires bite people sometimes (a Nicaraguan woman shows the tiny wounds on her toes that are the bat's mark), but they are not a major problem of public health. A few people do die each year in all Latin America from the bite of some rabid bat. The delicious threat of the scary vampire is brought under reason as a genuine but limited danger to us and to our dependent species, danger from "a fascinating real creature that happens to need blood in order to fly, to raise its young, to live," through a virus—the third party.

THE PLANTS WE EAT, by Millicent E. Selsam. Photographs by Jerome Wexler and others. William Morrow and Company ($8.95). Something is told here of how oats, peas, beans and barley grow, and a good deal about pineapple and chocolate, tomatoes and bananas, figs and tabasco peppers, and many more. Firmly but not pedantically botanical, the readable text for fourth or fifth grade and up divides our vegetable diet into roots such as the carrot, stems such as the potato, leaves such as tea and tiny stem-hugging Brussels sprouts, flowers such as the thistly artichoke, fruits such as cocoa and chili, and seeds such as the staple grains. The sharp photographs of Jerome Wexler help the reader to perceive the food on the plate as once part of a growing plant, often through tight closeup shots.

Meanwhile a bit of economic history enlivens the botany in a fine beginner's guide to the basis of our lives together in this world fed from field, garden and orchard. It is a nice story that in 1820 Robert Gibbon Johnson calmly ate a basket of fresh tomatoes right there on the courthouse steps in Salem, N.J., before an aghast crowd. No one would touch the fine red fruit he offered them. Of course people from Peru to Mexico had enjoyed tomatoes for many centuries, and by that time Europe too had long realized how far from poisonous these nightshade relatives are. The new compilation of text and photograph is one more of this veteran partnership's first-rate eye-openers for children who read.

CHICKENS AREN'T THE ONLY ONES, by Ruth Heller. Grosset & Dunlap ($5.95). On the large pages of this thin volume on certain easy facts of life, meant for the still read-to and the new reader, glowing images show white hen's eggs and decorated ones, peacock and frog, dinosaur and sea horse, a ray and its mermaid purse, an octopus and a few dozen of her bluish egg strands, and more. Somehow it all looks quite real, although at the same time it is pleasing in composition, color, interplay and design. The text is very small, mostly one couplet to a page. Two pages swarm with insects, and finally we learn about some animals that do not lay eggs. They are known as mammals or mammalia, but there are two exceptions, and they both live in Australia! (The verse is splendidly bouncy like that throughout, except that on the next to last page one foot is somehow missing.)

Technology Past and Present

KITES TO MAKE AND FLY, by David Pelham. Ten original paper cutout kites. Penguin Books ($14.95). Printed in brilliant colors on heavy stock, spreading across the big pages nearly a foot and a half by a foot, 10 original kite designs lie ready. Equipped with a knife, a ruler, a tube of airplane-model cement, a few odd items, maybe some tail material and a spool of strong white thread, a reader able to cut with care can release any of these designs into the wind, some after 15 minutes, some after an hour. Tubes, fins, pleats, multiple bridles—these are not commonplace forms, but they fly, and fly well, each in a range of wind speeds given for the design, from the very lightest breezes up to fresh winds.

The gifted kitesman who prepared this unusual book is an English art director already distinguished by a kite book (also published by Penguin) reviewed in these pages six years ago. This time, with a few good pages on theory and even better ones on flying technique, he has left aside the history and set forth careful procedures that beginners can fully use, although they must be deft of knife and glue. A group of kite hopefuls could share the cost easily and find themselves with kites of beauty, style and performance. These kites are small as kites go, and they are tethered not by string but by thread, but it is entirely possible to fly them 1,000 feet high out of sight! One would not be likely to do so, but the excess certifies the design. More advanced kite makers will get design suggestions from Pelham's virtuoso schemes, one of which goes back to that remarkable Neapolitan scientist of the 16th century, Giambattista della Porta.

OUR MODERN STONE AGE, by Robert L. Bates and Julia A. Jackson. William Kaufmann, Inc. ($18.95). Each American in this age of iron draws anew on the earth for about half a ton of the metal per year. But that same average consumer requires more than 10 tons per year of nonmetallic minerals, fuels aside. Ours remains in fact a stone age. We build in stone, although mostly not, of course, in the mason's cut blocks or even in freestone from the fields. Our structures are of biddable concrete and loose fill. Most of that material is limestone rock crushed to gravel, along with plenty of sand and natural gravel and a good amount of clay. Clay is essential to cement; some is baked to brick and tile. The finest white clay, pure kaolin, makes not elegant dishware but mainly coated paper, like that in your hand.

In this lively and pleasantly informal work the authors outline product by product and place by place the geology, manufacture and use of stone today. Here one can see the world's only open-pit mine of its kind at Boron, Calif., and note the rich gravel deposit mapped a few miles out to sea from Asbury Park, N.J., and 50 yards down, a bonanza for New York builders in the not very distant future. Diamonds and diatoms, blasting and draglines, occupational safety and the dilemma of the rational use of land all find vivid account here. The authors are up-to-date, and they treat their topic not as an outline of dry facts but as a glimpse of an unexpected but indispensable part of our life in an industrial land.

The phosphate gravels of Florida nourish our crops, and the sulfur of the Gulf salt domes makes that phosphorus soluble. Most unexpected is the fact that soda ash, the sodium carbonate of commerce, a major ingredient of glass, paper and soaps and detergents of all kinds, has lately reversed nearly two centuries of industrial history. Modern industry since its inception in James Watt's England has sought better ways to make alkali than by burning wood or kelp to ash. The names first of Leblanc and then of Solvay became famous for large-scale processes to get soda ash from salt, lime and ammonia, long hallmarks of heavy chemical production. By 1979, however, only one Solvay-process plant remained at work in the U.S., where before World War II there were 17; now the stuff is mined deep under the Green River Basin of Wyoming, where it was accumulated long ago by the tens of billions of tons from a soda volcano, rather like one or two active today in the East African Rift. The cheap natural substance swiftly replaced the expensive synthetic. Serious readers from junior high to senior citizen will enjoy this informative, thin, readable volume.

THE PUZZLE OF BOOKS, by Michael Kehoe. Carolrhoda Books, Inc., Minneapolis, Minn. ($6.95). Books look simple enough, just type on a white page. But actually every book is a kind of jigsaw puzzle, fitted together out of many details by many people working together, although often separated in space and time. That is the topic of this direct little story, which follows one real children's book, a book physically like itself, along the long chain from an author's hopeful covering letter to the publisher with her manuscript and a self-addressed stamped envelope enclosed, to a smiling reader nearly a year later enjoying *The Story of Cadmus.* First of all comes an editor and the crucial decision to go ahead. Then the editor goes to work on the text. Enter the artist at the editor's call. After much consultation the artist prepares a "dummy" of the entire book, with sample sketches on the pages where he wants them. The production manager and the designer take over; the designer will choose the paper and the typeface, with headings and special initial letters.

In time the typesetter at her computer console is sent the final text; her output is stored pulse by pulse on a magnetic disk. The disk is transferred to a second program disk; along with a typestyle disk of letters that the program can control the two disks inform the printing machine. Every letter of the text is projected in turn onto photographic paper; once the paper is developed the book is seen printed there, in one copy. Then the paste-up is prepared, with all the type and photocopies of the original illustrations cemented onto paper boards exactly in their final position. This work is done with particular care, because the paste-up is the model for the final book.

Now the paste-up is carefully photographed at exact size. The big sharp negatives—the cameraperson checks the details with a magnifier—come from a camera as big as half a room. The negatives are exposed to get a positive proof for a final check and are sent on to the printer. Again a photographic process duplicates all the images of the book onto coated aluminum plates. Developed and washed, those treated plates take up ink only where black should be. Then the printers go to work on their swift clattering press; as the drum with the plates begins to spin "the printer listens... like a doctor [listening] to your heart." Each hour of press run yields 6,000 printed sheets. The sheets move off to the bindery, for six or seven mechanized steps more. The dust jackets arrive, the books are then wrapped, warehoused and shipped to bookstore, school and library, where at last....

This is a pleasantly concrete account for young readers of the making of a familiar thing at small industrial scale. A dozen of the men and women who took part are shown, and even more are thanked. Of course, there are more complex bookmaking processes; books vary a great deal in size and in press run. This is one modest, up-to-date example, with type metal only a memory.

TALES ABOUT METALS, by S. I. Venetsky. Translated from the Russian by N. G. Kittell. Mir Publishers, Moscow. Distributed by Imported Publications, Inc., 320 West Ohio Street, Chicago, Ill. 60610 ($5.80). For two dozen elements from light lithium to heavy uranium every small chapter of this lighthearted book is labeled with the chemical symbol of a metallic element. In each essay (which in no way claims to be a "systematized account" of the history and uses of the metal) the author of this very popular Russian book, for any good reader with a chemical bent, assembles a charming account of one interesting metal. His tale frequently opens with classical accounts, from mythology or from "old Pliny," goes on to discovery, marshals a number of anecdotes and closes with modern uses and some optimistic projections into the future. He is plainly fond of technology and its promise, although he is alert enough to its dangers to observe that lead water pipes may have helped to do in Imperial Rome, and that "tetraethyl lead must be replaced by something else."

The stories range the world over; they are not provincial in tone, although of course one of the pleasures for an American reader is what one picks up about Russian technology, its heroes, its curiosities and its visibility in daily life. Those who win the prestigious Order of Lenin receive medals not of gold but of platinum; the obelisk in Moscow's Prospekt Mira, that commemorates the first cosmonauts is made of polished titanium sheets; a Siberian expedition at the turn of the century was quite well equipped except for the unhappy choice of tin cutlery, which the low temperature converted into a gray powder.

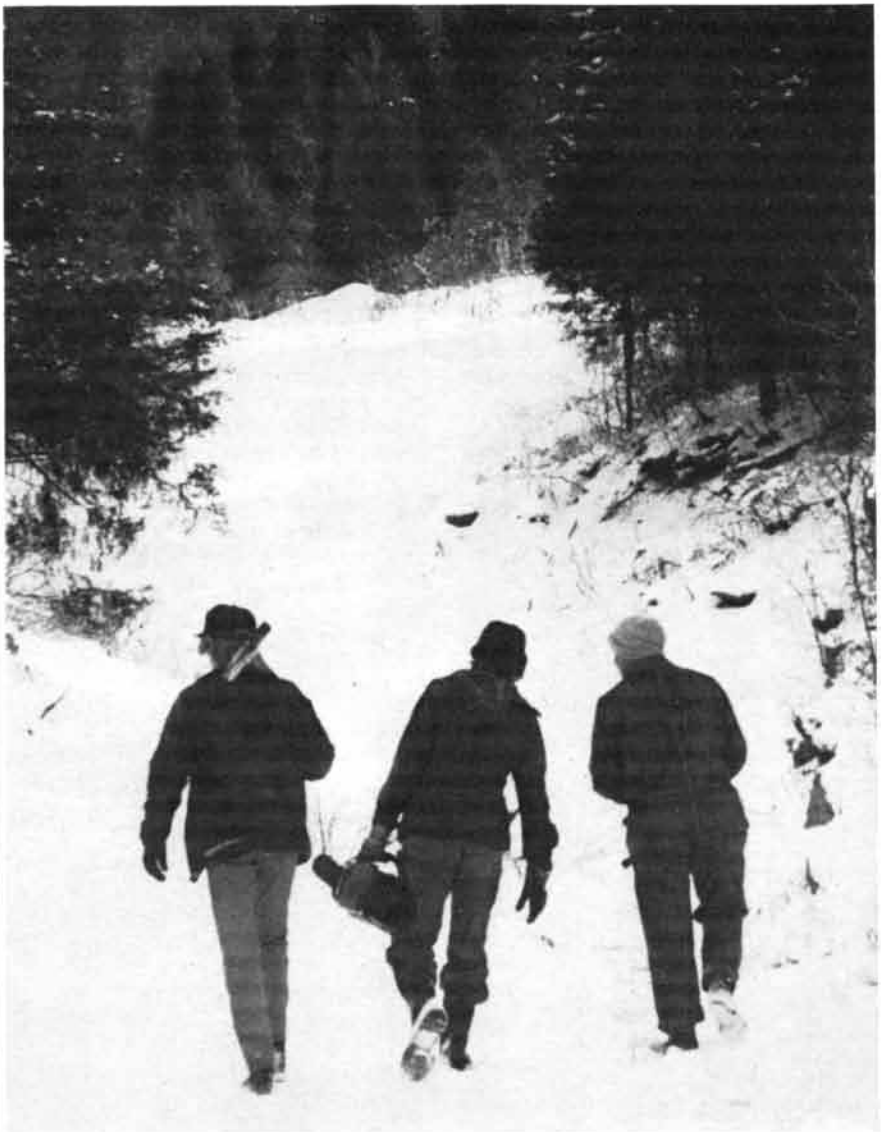
Nearly every page has an agreeable and relevant cartoonlike picture. (They are not ascribed, but perhaps they are the work of the talented author.) The material is not documented at all; whereas most of the stories are reliably factual it might be that now and again a grain of salt should accompany the author's cheerful example. He has in some instances relied on rather journalistic accounts. An American might place beside the fact that the great Mendeleev was given in London a chemical balance made of gold and aluminum, in the days when aluminum was a jeweler's metal, the remark that the very apex of our tall Washington Monument was fashioned of that same metal in the same era.

CATASTROPHES, by Walter R. Brown, Billye W. Cutchen and Norman D. Anderson. Addison-Wesley Publishing Company, Inc. ($6.95). Grim yet fascinating, fire and flood, snowstorm and hurricane, earthquake and volcano have always clawed at human lives and hopes. Catastrophic events are part of the common currency of our culture, particularly those that connect with popular experience by circumstance, time or location. This well-made compilation tells a journalist's tale of the *Hindenburg* dirigible disaster, the spread of the fire from that kerosene lamp kicked over in Mrs. O'Leary's barn to all of wood Chicago after the hot, dry summer of 1871, the earthquake and fire in San Francisco, the terrible eruption ascribed to Mount Katmai in the Valley of Ten Thousand Smokes, the 1938 hurricane across New England and quite a few other examples, with the familiar smothering of Pompeii as one example far away in space and time. It is good journalism, with the conversations and comment augmented by some effort at background. There are a wind-chill table and a Mercalli Scale of earthquake intensity, along with introductions to the meteorology of winter storms, hurricanes and tornadoes, and some account of the geology of volcanoes and earthquakes.

The freshest and most cheering event is the flooding of the Salton Sink, which nearly ended the grand scheme to make the ancient desert delta of the Colorado River into the great irrigated garden we now call the Imperial Valley. From the poetic old name of the basin, La Palma de la Mano de Dios (the Palm of the Hand of God), to the two-year effort of the Southern Pacific Railroad to stem the flood by dumping 3,000 60-ton carloads of rock to block the overflow of the Colorado, the entire chronicle is a pleasure. No one was killed, the railroad got its money back from land sales afterward and the irrigated desert still blooms, although the Salton Sea now rolls blue over 300 square miles of the old sink. Even for this young audience it is a pity no effort was made to suggest that these detailed stories are not fictional but rest on a demonstrable chain of human experience. Nor are sources cited for any of the other accounts, with the exception of credits for the illustrations and the names of people quoted. Otherwise this is a gruesomely nourishing work for grade school youngsters who like to read and to see beyond headlines.

Marco Polo, by Gian Paolo Ceserani. Illustrated by Piero Ventura. G. P. Putnam's Sons ($9.95). The fields of paddy rice stretch to the horizon, some green with the crop, others sheets of water mirroring the sky. Across the two-page spread the small bright procession follows the wide road across an arching bridge over the canal. The open countryside is evoked nicely by the painter, who works in convincing detail yet leaves most of the page paper white. You cannot miss the central actor; it is young Marco Polo, riding on the Great Khan's business in a closed crimson sedan chair borne by 16 coolies. Text and picture recount the ventures of the Polo family, from the market halls of Venice stocked with Damascus silk and bundles of sweet-smelling sandalwood to the eventual prison days of Marco's glowing tales.

There in front of the cathedral a little group is retelling Marco's travels with the aid of a drum and pictures spread out on a board, a 13th-century version of what the author and the illustrator have done for young readers today with



the help of the printer-craftsmen of Verona. Their book of 32 pages of paintings with its crisp and specific text conveys the sense of the great traveler's classic: the crowded ports of the Levant, the dusty wastes of the fearful Gobi, the enormous Buddha image and the nomad's yurt, and at last the colorful symmetries of the temples and the cultivated simplicities of the evergreen gardens of Khanbaliq. Paper money and a black stone that burns, printed books, fireworks, the compass and above all the lavish scale of Kublai's China are here drawn or described. Marco told of more than he had seen, but most of what he said was well reported. Columbus believed every word of it. We can concur, although the pair of spectacles shown here in a Chinese example are pretty surely out of period. They are a Tuscan invention quite new in Marco's days.

UNDERWATER DIG: THE EXCAVATION OF A REVOLUTIONARY WAR PRIVATEER, by Barbara Ford and David C. Switzer. William Morrow and Company ($9.50). In July of 1779 there set out from Boston for action in Penobscot Bay a naval force, the biggest yet mounted by the Americans, with warships of the Continental Navy and the state and a good number of the free-enterprise warriors called privateers. In spite of hero Paul Revere's being high in the command, the expedition met bitter defeat. A reinforcing British fleet put the Yankees to flight; most of the American ships were run aground and set afire by their own captains to escape capture along the shallows up the Penobscot River.

A 16-gun brig, the brand-new privateer *Defence,* was one such ship. All her company survived. The two authors are an expert science writer and a marine archaeologist who has spent half a dozen years in and around the murky waters of the bay and the even more complicated currents of restoration and laboratory reports. The *Defence* was found on the bottom in 1972 by an M.I.T. student sonar team and its divers, just about where the clues of old fishermen and even older letters had placed her.

This is the story, summer by summer underwater, winter by winter ashore in the piecing and cleaning and inquiry into the long-lost secrets that make up the patient, delightful work of archaeologists by land or sea. There is no chest of gold here. The treasure is real but subtler: insight into one of only four known wrecks from all the thousands of Colonial ships that once sailed out of ports from Maine to the Carolinas. The archaeologists found the expected and the surprising, cannon and cannonballs, the wood tags that marked title to the chunks of salt meat each mess group brought to be boiled in the ship's big cauldrons. The intimacy of the finds and the uncertainty of the entire search suffuse every lively page of the account. The hull is still down there, what was left after the fire; it would be too expensive to bring it up and maintain it on land. The knowledge, however, is safe ashore, along with many fascinating smaller pieces of wood, iron and lead, and with medicine, shoes, grapeshot and a navigation ruler. The ship below is now fully preserved through documentation, and many parts as big as cannon and heavy mast stumps are exhibited on the shore to aid understanding.

Maps, photographs and drawings are here, a sequence showing how the work grew into fine detail. Here too are the names of the expert staff and their team; most of this devoted and elegant work was done by a hundred young people, many of them students or summer volunteers. The sense of enduring connection with an emblematic past stands out in this informal account of archaeology, put in a way that should captivate adventuresome upper-grade divers into harbors and records alike.

Words and Pictures

THE CAT'S ELBOW AND OTHER SECRET LANGUAGES, collected by Alvin Schwartz. Pictures by Margot Zemach. Farrar Straus Giroux ($9.95). A German folklore journal in the 1890's asked its readers to send in any secret language they knew; 150 came in, perhaps the richest collection ever put into print. The Cat's Elbow, with a simple but tot-e-dod-iou-sos tot-o ror-ea-dod rule, was among them. A dozen more such enigmatic transformations are disclosed in this charming book, from pig Latin, a Russian children's tongue called Ku (which turns out to be a simple reversal of a familiar speech called Iggity), an inverting language from East Africa, an Amoy version called Sa-La (it will sometimes sound like tiny bells tinkling) to the rhyming cant of Cockney flash. There is a town in California where for half a century "almost everybody... spoke Boontling as naturally as they spoke English."

This small book provides much to enrich its strange linguistics. Not only is there a set of zany drawings in the spirit of it all but also there is a simply dazzling apparatus: the practice examples have written solutions and there are a couple of pages of interesting notes, a source or two for every scheme given and a fine long list of other books on secret languages. The tale of the Old Woman and the Pig in broadest Boontling should be an incitement to emulation by many a class and group.

AHA! GOTCHA: PARADOXES TO PUZZLE AND DELIGHT, by Martin Gardner. W. H. Freeman and Company ($15.95). Some deadly serious, some cheerily spoofing, about 80 paradoxes are here, usually set and then resolved in a couple of pages, often with a series of cartoon frames. They are taken from the chief domains of mathematics: logic, with its self-shaving barbers and lying Cretans; number, wherein one mark on a rod codes an entire encyclopedia and a certain large hotel has all its rooms filled and yet has plenty of vacancies; geometry, with its impossible objects and its disappearing personages; probability, in which Mr. Mark is always being taken and we encounter the profundities Pascal felt in his famous wager; statistics, where induction is glad to see even a nonblack noncrow and clumping arises (mysteriously?) out of pure randomness. The last section treats of time, as in the virtues of a stopped clock and the delights of tachyons.

Of course, many of these knots are well known, largely because Martin Gardner has so delightfully untied them for us over the years. The entire collection is an indispensable resource for any set of young argufiers. The categorized list of references forms a guide to a wonderland in print.

THE PRINCE WHO KNEW HIS FATE: AN ANCIENT EGYPTIAN TALE, translated from hieroglyphs and illustrated by Lise Manniche. The Metropolitan Museum of Art/Philomel Books ($10.95). The long desert yellow pages of this small book bear paintings in the very style and bright clear colors of the frescoes that still decorate many old walls along the Nile. Across the bottom of each page lines of hieroglyphs run like subtitles. The talented author-artist has rendered the story as she found it in an undecorated papyrus now in the British Museum, written on 3,000 years ago. She has given it new life in three ways: she has made the apt paintings to catch the eye, she has told the story well in our tongue and she has bravely added an ending—a fit and happy one because the scroll she followed is torn just where the fateful crocodile seizes the prince to bargain: "If you will take my side and kill the giant...."

To find out more about the prince's fate, about the dog, the serpent or the crocodile that alone might kill him, and about the lovely wife who saves him, seek out this book. The pages in which Lise Manniche tells us how she went about her revivifying work carry the story far beyond the fine tale-telling it is into the domain of archaeology, still within the grasp of readers in the lower grades. The narrative concludes: "With the help of the writer... the story has reached a happy end. Those who speak evil of it will have to contend with Thoth... the god of the scribes." What reviewer would challenge such an ancient and potent formula? Happily not one would be inclined to do so.

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DISTRIBUTION OF POPULATION in Europe is suggested by a nighttime photograph made in 1977 as part of the U.S. Air Force Defense Meteorological Satellite Program. On clear nights a satellite recorded light from the surface of the earth. The major sources of light are industrial concentrations and urban areas, which overlap to a large extent. Thus the bright areas in the photograph correspond to geographic areas with a high concentration of both industry and population. The correspondence is not exact, however, because some populous regions have more night lighting than others. In each country the region called the core includes most of the industry, much of the population and often the capital. The rest of the country makes up the periphery. The conspicuous bright area in northern France is the Paris basin, which is the country's core. The bright area to the north and east of Paris includes the core regions of Belgium, the Netherlands and West Germany. Belgium appears disproportionately bright because of the intense illumination of the Belgian highways.

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Migration between the Core and the Periphery

For centuries the heavily industrialized "core" regions of developed countries have drawn population from the nonindustrial "periphery." This long-standing trend was reversed for the first time in the 1970's

by Daniel R. Vining, Jr.

Since the beginning of the Industrial Revolution the transition from an agrarian economy to an industrial one has been accompanied in every country by an increasing concentration of the country's population. In North America, Europe and Japan the gathering of the population into the industrial centers continued long after a high level of economic development had been achieved. Before the industrial period the population outside the few major cities was distributed according to the productivity of the land. As the demand for agricultural labor decreased and the demand for industrial labor increased, the inhabitants of rural areas moved to the cities in large numbers. As a result the distribution of population in the industrialized countries became increasingly uneven. Populous metropolitan areas became distinct from the sparsely peopled "hinterland." On a larger geographic scale entire regions became centers of industry and commerce while other regions retained an agricultural character.

The primary industrial region of a country, with the greatest density of population, I shall designate the core. The remainder of the country, with a lower density of population, I shall call the periphery. For example, the Paris basin is the core region of France; the rest of the country is the periphery. In the U.S. the traditional industrial areas of the Northeast and the Middle West constitute the core, with the South and the West making up the periphery. In most cases the core region of a developed country is centrally situated, and it is always accessible to the periphery and to the country's major trading partners. The core includes the largest cities and usually the capital. Because of the connections among economic vitality, population growth and political power, the core is often politically and culturally dominant within the nation.

From roughly 1750 until the end of World War II in all countries where industrialization had begun the core expanded at the expense of the periphery. Since 1945, however, and particularly in the 1970's there has been a dramatic reversal in the pattern of migration in the economically developed countries. In many of the richest countries of the world the direction of net internal migration is no longer from the periphery to the core. In the U.S., where the reversal began first, and in Canada there is now a substantial flow of people from the core to the periphery. In the industrial countries of continental northwestern Europe the flow is also toward the peripheral regions, although it is smaller. In much of the rest of western Europe and in Japan migration into the core has decreased to a level that yields an approximate balance between migration into and out of the core.

In eastern Europe there is still migration into the core. In the Third World, where economic development is less advanced, migration into the core regions is still substantial. Thus there is now a considerable difference between the pattern of internal migration in the developed countries and the pattern in the developing ones. This abrupt change in a fundamental demographic trend was not foreseen by social scientists; indeed, it remains largely unknown outside the small group of economists, geographers and demographers who are studying it. The migration from the core regions that began in the 1970's may be the first indication of a new form of demographic organization characterized by a more even distribution of population and political power than the one that currently prevails in industrial societies.

For the past 10 years I have been collecting data from 22 countries on internal migration. I have divided the 22 countries into five groups on the basis of the migration patterns; as it turns out, the groupings are also to a large extent geographic. In the first group are Canada and the U.S. In the second group are five heavily industrialized countries in northwestern Europe: Belgium, Denmark, France, the Netherlands and West Germany. The third group includes the outlying countries of western Europe and two developed countries in the Pacific: Britain, Finland, Iceland, Italy, Japan, New Zealand, Norway, Spain and Sweden. There are four countries from eastern Europe in the fourth group: Czechoslovakia, East Germany, Hungary and Poland. South Korea and Taiwan make up the final group.

The 22 countries in my sample include many of the wealthiest and most economically advanced nations and a smaller representation of nations at a somewhat lower level of economic development. The data I have employed to calculate interregional migration rates come from national censuses and from the registers of population that are maintained in most European countries and in Japan, South Korea and Taiwan.

The registers are kept in each administrative district such as a province or a prefecture. On moving to a new area a citizen must register his address; his old address and region are recorded at the same time. In addition vital statistics such as records of births and deaths are entered in the registers.

The registers therefore provide a count of the population of each administrative unit every year. The record of the people who have moved into and out of the area in the year can be utilized with the population count to calculate the annual rate of migration between regions. By combining the appropriate administrative areas an approximation of the core region in each country can be constructed and the rate of migration between the core and the periphery can be determined. Of course, the boundaries of the combined administrative units do not coincide exactly with those of the core. By a careful choice of areas, however, a good approximation of the core can be constructed.

Analyzing the population of official administrative areas rather than that of the actual core region can have certain advantages. It has been suggested that the current migration out of the core in the developed nations represents no more than the expansion of the established core into adjacent areas. By selecting the right official areas a region larger than the actual core can be defined. If there is a net migrational flow out of such an "overbounded" core, it lends considerable strength to the hypothesis that what is happening is a shift away from the existing core rather than simply a spilling over into contiguous regions.

In order to understand the significance of the change in the direction of internal migration that took place in much of the developed world in the 1970's it is necessary to understand why national populations first became concentrated. To explain why the growth of industry leads to demographic concentration economists have postulated that there are economies of scale in the organization of an industrial society. An economy of scale is the saving that results from making an investment in an area where the scale of enterprise or the concentration of people and industry is already high. The existence of such economies implies that the return on an investment made in the core is higher than the return on an investment of the same size made in the periphery.

The economies of scale apply both to private investment and to government investment in public services. Such services as schools, roads, hospitals, sewage and drinking-water systems and fire-protection and police forces make up what is known as the infrastructure of industry: the services that do not enter directly into the processes of production but without which industry could not exist. To understand how economies of scale affect public investment consider the situation of a developing country that must decide whether to build a new high school in the core or in the periphery. The cost of the school building would be approximately the same in both regions. In the core, however, there are already buses to take pupils to the school, roads on which the buses can run, a pool of trained teachers and elementary schools to prepare pupils for high school education.

In the periphery some or all of these supporting elements would have to be brought into being before the first class could graduate. For this reason the cost of the first graduating class would be considerably higher in the periphery than it would be in the core. Analogous arguments apply to other public services. Geographic disparities in the infrastructure are particularly telling early in economic development, when the amount of capital that has been accumulated in a society is small.

The economies of scale for private investment in the core are also substantial. In the emerging core region there is a large skilled labor force. There are efficient systems of transportation for both workers and goods. Early in the industrial period, when heavy industry was dominant, railroads for transporting raw materials and finished goods were of particular importance; there are many more rail lines in the core than there are in the periphery. Furthermore, in the urban centers large markets are close at hand for both consumer goods and capital goods. A wide range of secondary businesses are easily accessible, including not only suppliers of parts and raw materials but also law firms, engineering services and public-relations firms. When communications systems were limited, the proximity of large enterprises to one another in the core provided an opportunity for sustained contact between business leaders.

As a result of the economies of scale most new industrial plants are built in the core as a nation industrializes. The presence of industry attracts ancillary businesses. The population of the core begins to grow as workers are attracted by the high wages offered there. Because of the higher population density public investment is also greater in the core. At a certain level of development the economic and demographic growth of the core becomes self-reinforcing.

The underlying cause of the uneven distribution of population in a devel-

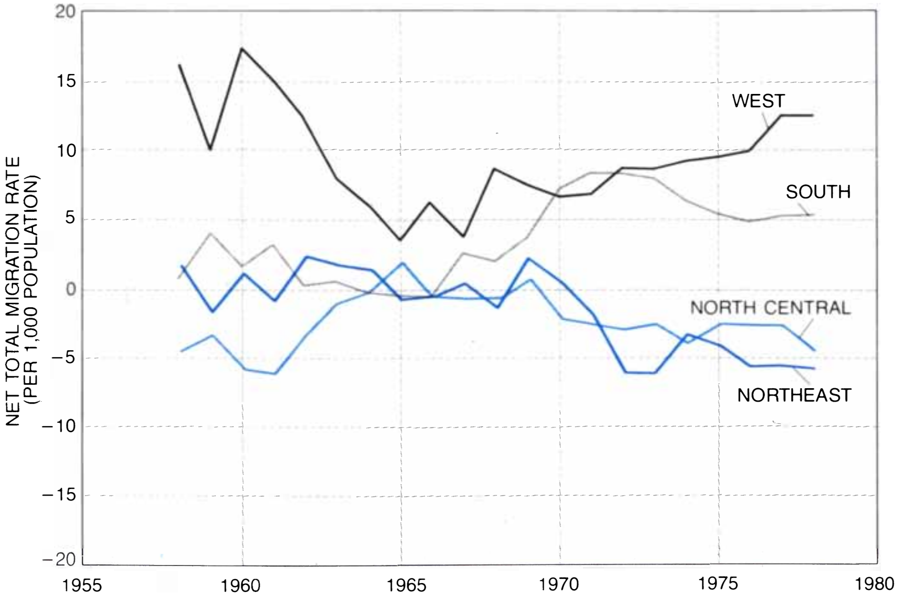
CORES OF THE U.S. AND CANADA are shown on a map of the two countries. The core regions generally accepted by geographers and economists are shown in dark color. The U.S. core comprises the older industrial areas of the Northeast and the Middle West. The core of Canada is an industrial region that borders on the U.S. In his work the author relied on official data on internal migration from 22 countries. The data are maintained for administrative units such as states, provinces and prefectures. The official units were combined to yield the approximations of the core shown in light color. In the U.S. the core defined in this way includes the North Central and the Northeast census regions; the periphery is the South and the West census regions. In Canada the core is the Center region; the Atlantic provinces and the West are the periphery. The approximations thus include an area larger than the actual core. That there is net migration out of the larger areas shows the sharp change in migration is a reversal of the established trend and not just a spillover of population from the core into adjacent areas.

oped country is therefore primarily economic. The American statistician Adna Weber, who worked as a public servant in New York, was one of the first people to study the growth of urban areas statistically. Weber's succinct formulation of the mechanism of population growth in industrial areas was the following: "When the industrial organization demands the presence of laborers in particular localities in order to increase its efficiency, laborers will be found there; the means of attraction will have been 'better living....' Economic forces are therefore the principal cause of the concentration of populations in cities." That demographic and industrial concentration results in the most productive utilization of resources in a society and hence in the greatest wealth for the nation has become a fundamental postulate of urban economics and economic geography. The concept has been emphasized by a number of scholars, including Edward L. Ullman of the University of Washington, William Alonso of Harvard University, Colin Clark of the University of Queensland in Australia and Koichi Mera of the University of Tsukuba in Japan.

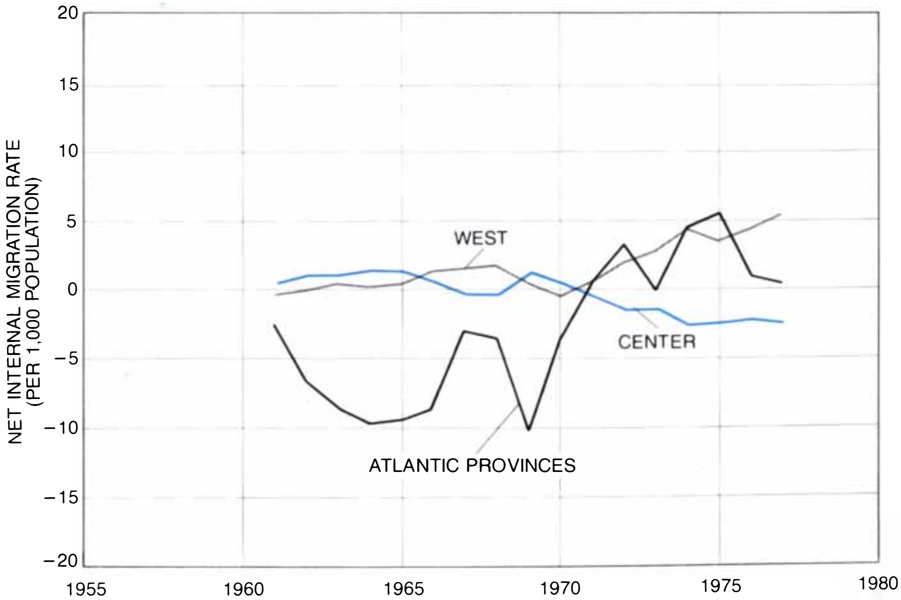
It appears, however, that at some point in the process of economic development the economic advantages of scale begin to decrease. The reduction seems to have come earliest and been strongest in the U.S. As I noted above, the core region of the U.S. is made up of the older industrial states of the Northeast and the Middle West. It was the first core in the developed nations to have a net loss of people to the periphery as a result of migration. The U.S. core has had a net outflow in its exchange with the U.S. periphery since 1945.

Until 1970 the net loss of people from the core region of the U.S. to the periphery was generally small. In the 1970's, however, the migration accelerated rapidly to a rate of at least 400,000 per year. This rate, which is the highest in the developed countries, has been calculated from the intercensal estimates of population made in the 1970's by the Bureau of the Census. Unfortunately (for the purposes of economic geography) the U.S. maintains no register of population. Although detailed information on internal migration is collected in the decennial census, the results are not yet available from the 1980 count. Moreover, sources other than the census provide only a sketchy account of where immigrants from abroad settle in the U.S. For this reason information from the 1970's on trends in the population of the regions of the U.S. includes the effects of immigration as well as those of migration between regions.

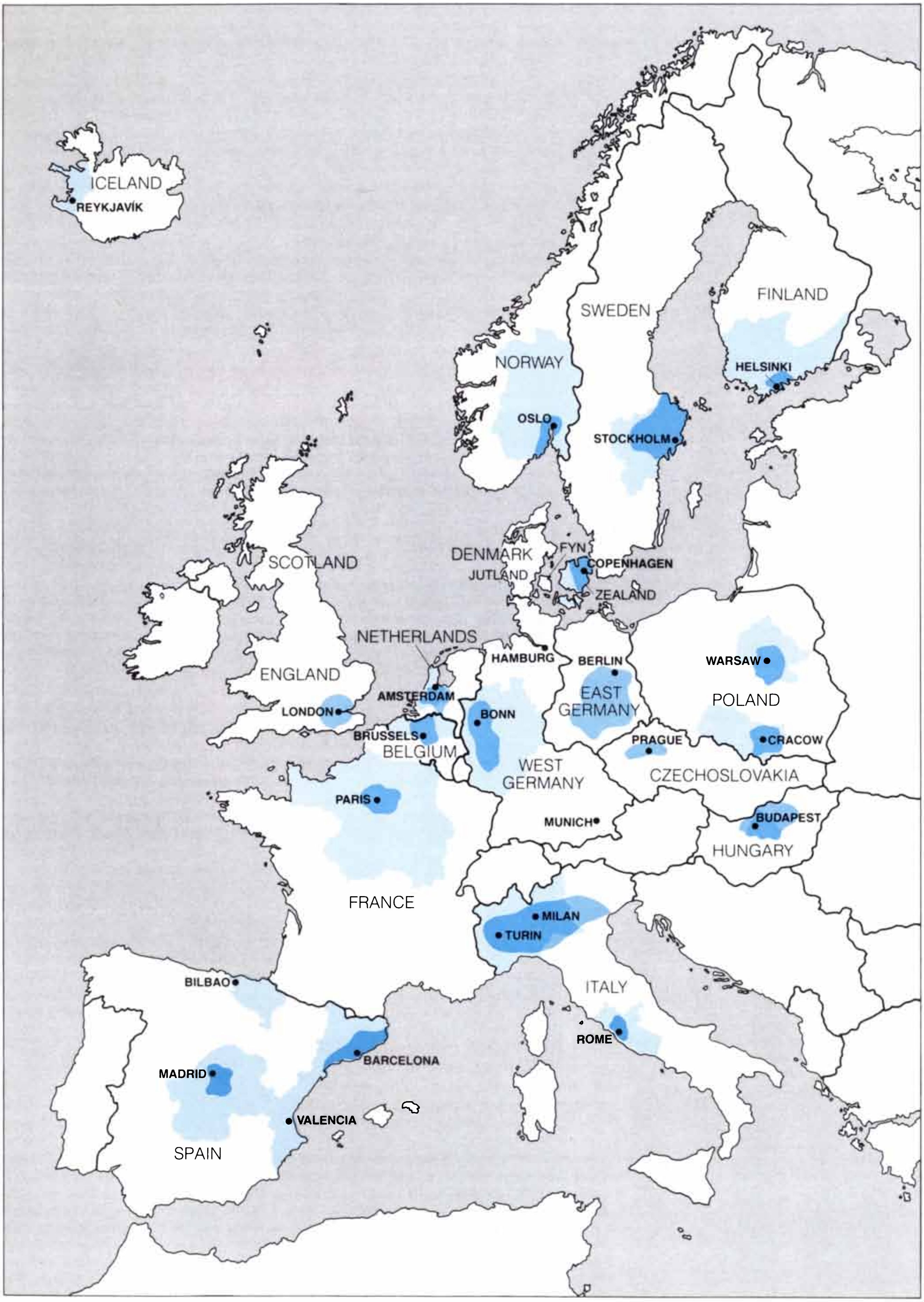
The rate of 400,000 people per year is therefore undoubtedly an underestimate of the actual net migration from the U.S. core. Immigration from abroad



MIGRATION RATES FOR U.S. REGIONS are given in terms of the net inflow or outflow per 1,000 residents of each census region. Where the net rate is positive the region gained population by migration, where it is negative the region lost population. The U.S. was the first country in which the direction of migration changed. Since 1945 the U.S. core has consistently lost population to the periphery. The loss now amounts to about 400,000 people per year. Because information on internal migration from the 1980 census has not been released the graph is based on other data that include the effects of immigration from abroad. Actual losses from the U.S. core to the South and the West are probably larger. Early in economic development industry becomes concentrated in the core because of the economic advantage of building a factory in an existing industrial center. Such advantages are economies of scale; they arise in part from the proximity of markets and labor pools and from efficient systems of transportation and communication. Population follows industry. Later in development economies of scale are reduced; industry and population begin to flow to the periphery. One reason for the early and large flow from the U.S. core is that the South and the West are well suited to industry.



MIGRATION RATES FOR CANADIAN REGIONS reveal a reversal in the past decade. Unlike the data for the U.S., only internal migration is included. In the 1960's the Canadian core generally gained people from the periphery. In about 1970, however, the industrial centers began to lose people to the periphery. As in the U.S., the periphery in Canada is well suited to industrial development. When improvements in transportation and communication and changes in industrial processes made it possible to put industrial and other facilities outside the core, the Canadian periphery grew rapidly. Much of the internal migration in Canada has been to the economically expanding West. Recently, however, the Atlantic provinces, long a "lagging" region economically and demographically, have also begun to draw people from the core.


ICELAND
REYKJAVÍK
FINLAND
SWEDEN
NORWAY
HELSINKI
OSLO
STOCKHOLM
SCOTLAND
DENMARK
FYN
JUTLAND
COPENHAGEN
ZEALAND
NETHERLANDS
HAMBURG
BERLIN
WARSAW
ENGLAND
AMSTERDAM
EAST GERMANY
POLAND
LONDON
BONN
BRUSSELS
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MILAN
TURIN
BILBAO
ITALY
ROME
BARCELONA
MADRID
VALENCIA
SPAIN

to the Northeast is substantial and has probably been increasing in the past decade. When detailed census returns are available and the effects of immigration can be separated from those of internal migration, the net loss from the core will in all probability be substantially greater than 400,000 per year.

In addition to internal migration and immigration the population of a region is obviously affected by the rate of natural increase, which is equal to the difference between the number of births and the number of deaths in a given period. The three demographic processes can augment or attenuate one another. As we shall see, in some countries a reduction in the population of the core resulting from migration has been obscured by a rate of natural increase in the core that is higher than the average for the country as a whole. Furthermore, counts of a country's total population are much more readily available than data on internal migration; this is one reason the reversal in migrational flows has attracted relatively little attention from social scientists.

The core area of Canada as defined in my work consists of the provinces of Ontario and Quebec. These provinces include Ottawa, the national capital, and Toronto and Montreal, the major cities. The actual core of Canada, as it is generally defined by geographers and economists, is a smaller area that borders on the U.S. In the 1960's the Canadian core drew people from the rest of the country. At the end of the decade, however, there was a sharp decline in the rate of movement into the core region. Early in the 1970's the decline was converted into a net flow to the periphery; the outflow continued throughout the 1970's.

As in the U.S., a large proportion of internal migrants in Canada move to the western part of the country. Even the coastal provinces of Atlantic Canada, however, which have long had a low rate of population growth and great economic difficulties, are now gaining population from the densely settled core. Although most immigrants to Canada settle in Ontario or Quebec, the substantial net migration out of the core has resulted in a rate of population growth there that is less than that of the nation as a whole. Hence in Canada internal migration has become large enough to outweigh both immigration and natural increase.

In the heavily industrialized countries of northwestern Europe the loss of attractive power in the core led to a net outward migration in the 1960's and 1970's. The core in the Netherlands, which is known as the Randstad, lies on the country's west coast. It has for some time been expanding to the southeast, toward the industrial centers of West Germany. It has been suggested by the urban theorist Hans Blumenfeld that the net migration out of the Randstad that began in the 1960's was only the southeastward extension of the established core area. My data show, however, that even the remotest areas of the Netherlands are currently gaining population at the expense of the Randstad. These areas include the north and the southwest, which for many decades have been "lagging" both economically and demographically.

Similarly, in Denmark, Belgium and France long-standing flows of population have recently been reversed. In Denmark internal migration has consistently been eastward from rural Jutland and Fyn to Copenhagen and the adjoining areas of the island of Zealand; there is now a considerable flow in the opposite direction. In Belgium the densely populated northern province of Flanders is now losing residents to Wallonia, the less densely populated southern province. Flanders includes the urban area around Antwerp, Brussels and Ghent that has been the demographic center of Belgium.

In France the census of 1975 showed that from 1968 to 1975, for the first time since record keeping began, the Paris region and basin lost more people to the rest of France than it gained. The Mediterranean provinces in the south of France have drawn people since 1945. In the early 1970's, however, the predominantly rural western part of France also began to gain people from the predominantly urban eastern part of the country, a phenomenon unprecedented in French history since before the beginning of the industrial era. Nevertheless, in both France and Belgium the core continues to attract a disproportionate share of immigrants from outside the country; the core populations also have a higher rate of natural increase than the population of the periphery has. The fraction of the national population living in the core has therefore generally continued to increase. The most recent intercensal estimates in France, however, suggest that the population of the core has begun to decline as a fraction of the national population.

In West Germany the extremely dense industrial area between the Rhine and Ruhr rivers constitutes the core. The Rhine-Ruhr region began to lose population to the rest of West Germany in the 1960's, before the reversal had got under way in the other industrial countries of Europe. Although the population of the Rhine-Ruhr district is very dense, the population of West Germany is somewhat more evenly distributed than that of most other industrial countries; the two largest cities in the country, Hamburg and Munich, are in the periphery. The relatively even distribution may partly account for the early reversal of net migration.

As I have mentioned, the concentration of industry and population in the core is caused largely by the economies of scale. The fact that migration into the core of developed nations has been replaced by a flow toward the periphery suggests that the economies of scale have been reduced. Several factors could have acted to reduce them. Perhaps the most significant factor is technological development, which has changed the bases for deciding where industrial plants are built.

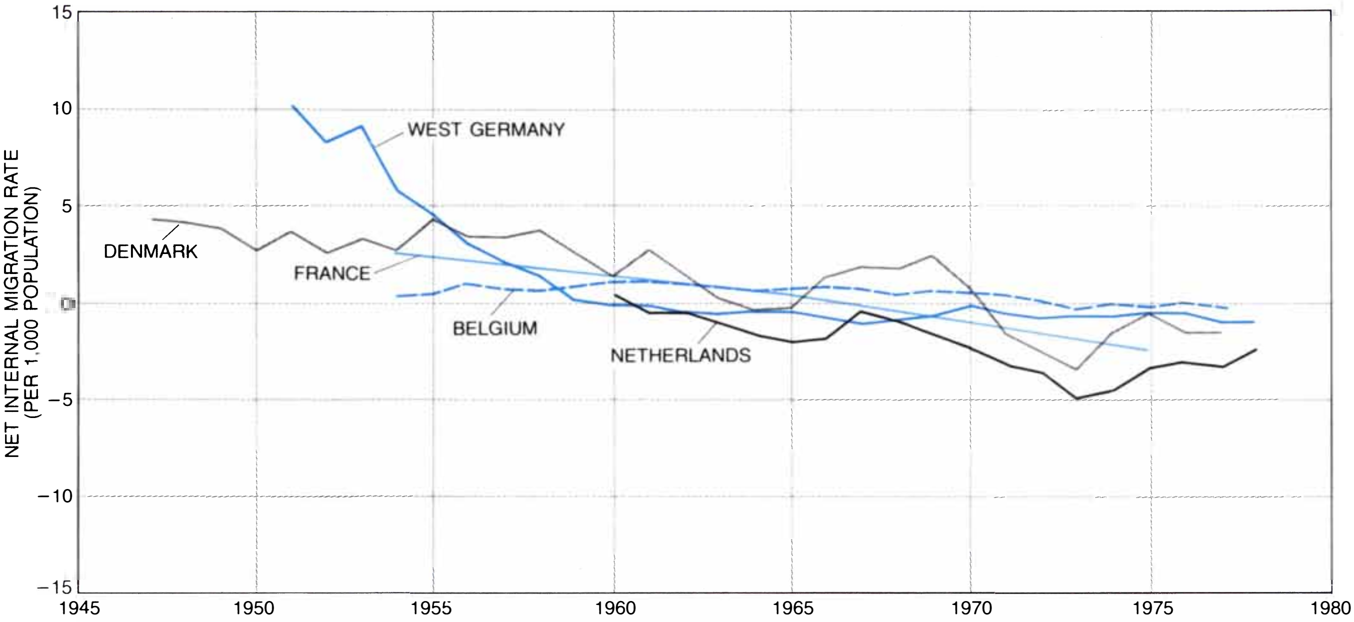
In the developed countries in recent decades much of the productive investment has been in the manufacture of goods incorporating advanced technology; an example of such a product is a small computer. The considerations in deciding where to build a plant making small computers are quite different from those in deciding where to build a steel mill in the early stage of industrialization. The components of high-technology products are generally small and light, as are the finished products. With improvements in transportation, particularly the building of highways, it has become cheap and convenient to haul component parts from distant sources and to transport finished products to distant markets.

The work force in most such plants is small. The importance of proximity to a large pool of skilled labor is there-

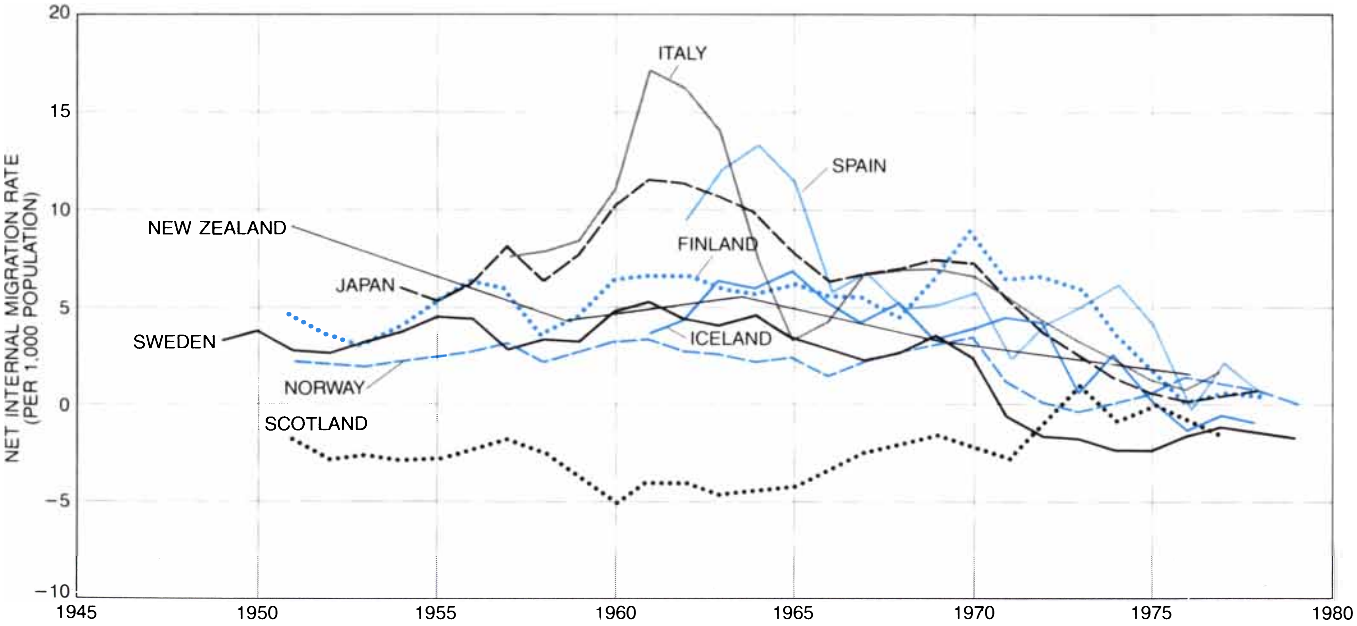
CORES OF EUROPEAN COUNTRIES in almost all instances include the capital as well as the major metropolitan areas. The true core is shown in dark color, the approximate core made up of administrative units in light color. The European countries in the author's sample can be divided into three groups on the basis of their migration patterns; the groupings are also largely geographic. In the first group are five industrial countries of northwestern Europe: Belgium, Denmark, France, the Netherlands and West Germany. In these countries there is now a net flow of people away from the core. The Rhine-Ruhr region, the core of West Germany, is the preeminent industrial concentration in Europe. The population of West Germany, however, is more evenly distributed than that of other industrial nations; Hamburg and Munich, the largest cities, are in the periphery. The second group includes the remaining western European countries (Britain, Finland, Iceland, Italy, Norway, Spain and Sweden) as well as Japan and New Zealand. In these nations the rate of migration into the core has declined, but only to the level that yields an approximate balance between migration into and out of the core. Reykjavik is the true core of Iceland. The third group includes four eastern European countries: Czechoslovakia, East Germany, Hungary and Poland. Here there is a flow into the core. East Berlin is the core of East Germany and Prague that of Czechoslovakia as approximated by the author.

fore reduced. Improvements in communications have made it possible for manufacturing companies to be situated far from the companies that provide secondary services. When a high level of economic development has been reached, enough capital is accumulated to allow the infrastructure to be built up in the peripheral regions. Schools, roads, hospitals and fire departments in the southwestern U.S. or western France are comparable to those in the core. In addition the growth of the service sector has contributed to the reduction of the economic advantages of the core; geographic constraints on the location of service companies have been greatly reduced by advances in communications.

The economic advantage the core has over the periphery has thus been reduced by several factors. Moreover, in a



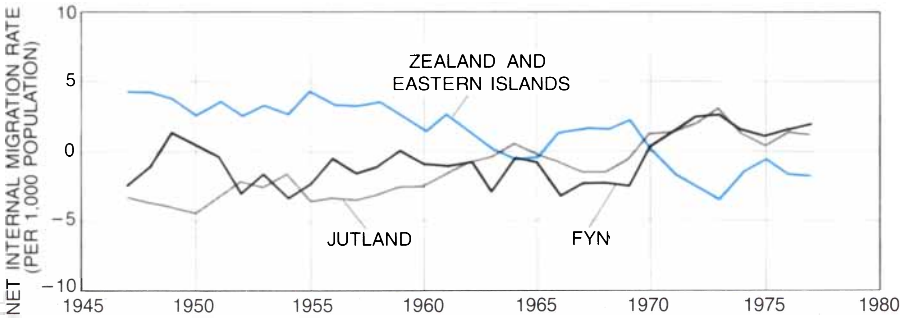
FIVE INDUSTRIAL COUNTRIES of northwestern Europe show the earliest decline in migration into the core outside North America. Each curve represents the net migration rate for the core of one country. The decline began first in West Germany, in part because of the relatively even distribution of population there. By the 1960's migration had declined in all five nations; by the late 1970's a net outflow from the core had resulted. Peripheral regions that had lost population to the core for decades, such as the northern Netherlands, are now gaining population by migration. One reason for the outflow is that the peripheries of these countries have good sites for industry.



OTHER WESTERN EUROPEAN COUNTRIES together with Japan and New Zealand have a migration pattern different from the one in the industrial countries of continental northwestern Europe. In many of the outlying European countries the rate of migration into the core reached a maximum in the 1960's and began to decline significantly only in the 1970's. Furthermore, in most of the countries in this group there is as yet no net outflow of people from the core. In some countries (such as New Zealand) economies of scale are still substantial. In others (such as Norway) the periphery is poorly suited to industry. In Britain complete data on internal migration after World War II are available only for Scotland. Because Scotland makes up a significant part of the periphery in Britain, however, the rate of migration from Scotland shown in the graph can stand as a mirror image of the movement into the core region in the southeast.

very dense urban area some of the economies of scale can be transformed into diseconomies. For example, many manufacturing processes call for a single-story building occupying a substantial tract of flat land. In urban areas flat land is expensive; in the less developed periphery building costs are considerably lower. Labor organizations in the core raise wages above the rate prevailing in the periphery. The high population density can lead to congestion on roadways, which becomes an impediment to industry as trucks carry an increasing share of the freight traffic. The core also has high insurance rates, environmental pollution and social uncertainties.

Diminishing economies of scale can induce industry and commerce to shift their locale, however, only if the periphery has suitable sites for factories, businesses and housing. The U.S. is the best example of a country with a periphery that is equal to the core in physical assets, if not superior.



MIGRATION BETWEEN REGIONS OF DENMARK shows there was a reversal in the prevailing direction of internal migration in the 1970's. The major land areas of Denmark are the eastern island of Zealand, on which Copenhagen is situated, the central island of Fyn and the western peninsula of Jutland. For many decades economies of scale were large and the predominant flow of population was eastward from rural Jutland to Copenhagen. The core region employed in the author's work includes Zealand and several small nearby islands; it is thus larger than the actual core. Since 1970 this large area has consistently lost population by migration. In the same period Jutland has begun to draw people from the core; Fyn is also gaining population. The net migrational flow is now westward, and for the first time in this century the rate of population growth in Jutland is greater than that of Denmark as a whole. Similar reversals have been detected in Belgium, France and the Netherlands. A factor in bringing about the reversals has been the advent of industrial processes based on advanced technology. Many products of advanced industries are easily transported; the work force is small, but the plants require a substantial area. Hence it is advantageous to build new plants in peripheral areas.

None of the other countries in the developed world has a periphery with unexploited physical resources as great as those of the U.S. periphery. This is the main reason the rate of migration from the core in other countries has been smaller than the rate in the U.S. The periphery of the countries of northwestern Europe does, however, have sites suitable for industry and settlement. The climate, soil and topography of southwestern France, Jutland, the northern Netherlands, Bavaria and southern Belgium are appropriate for urban and industrial development; so are conditions in the western provinces of Canada. While the economies of scale remained substantial these areas stagnated economically. Since the advantages of scale have been reduced or even become disadvantages the peripheral regions have begun to exert a strong attraction for both commercial ventures and population.

The nine countries that make up the third group in my sample (Britain, Finland, Iceland, Italy, Japan, New Zealand, Norway, Spain and Sweden) show a pattern different from the one in North America and northwestern Europe. In these nations the rate of migration into the core reached a maximum in the 1960's, somewhat later than in the other groups, and it began to decrease significantly only in the 1970's. A more important distinction is that in Japan, New Zealand and the outlying countries of western Europe the decline in the rate has not in most instances resulted in a net loss of population from the core. Instead the migrational flow has tended to decrease and then suddenly level off, leaving either a balance between movement into and out of the core region or a small net migration into it.

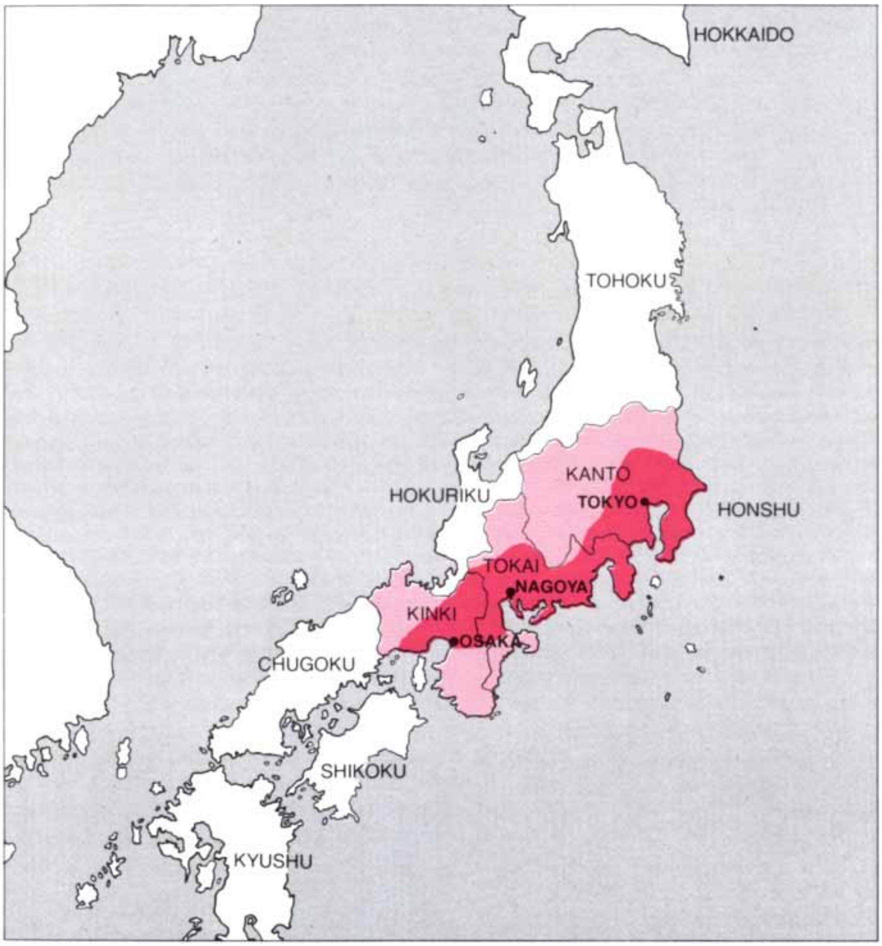
The overall rate of population growth in the core in the third group of countries remains greater than that of the nation as a whole. Nevertheless, the significance of the decline in the net migration rate in countries such as Italy, Japan and Sweden should not be underestimated. In these nations geographers, economists and urban planners had thought it would be impossible to stem the flow of people into the densely populated core and halt the depopulation of the periphery. The data indicating that a balance was being approached or had been achieved were met with amazement and in some instances with skepticism.

Why has the direction of net migration in the countries of the third group not reversed, as it has in North America and northwestern Europe? In all probability what is responsible is a scarcity of sites for development outside the industrial regions. In each of these countries (with the possible exception of New Zealand) the periphery is at a clear geographic disadvantage with respect to the core. For example, in Norway the periphery has little flat land, and what it has is broken up into small parcels by mountains and fjords. In northern Norway the summers are cool and damp; winters are long, dark and frigid. Such conditions make it difficult to build cities, factories and roads and to attract and keep a work force.

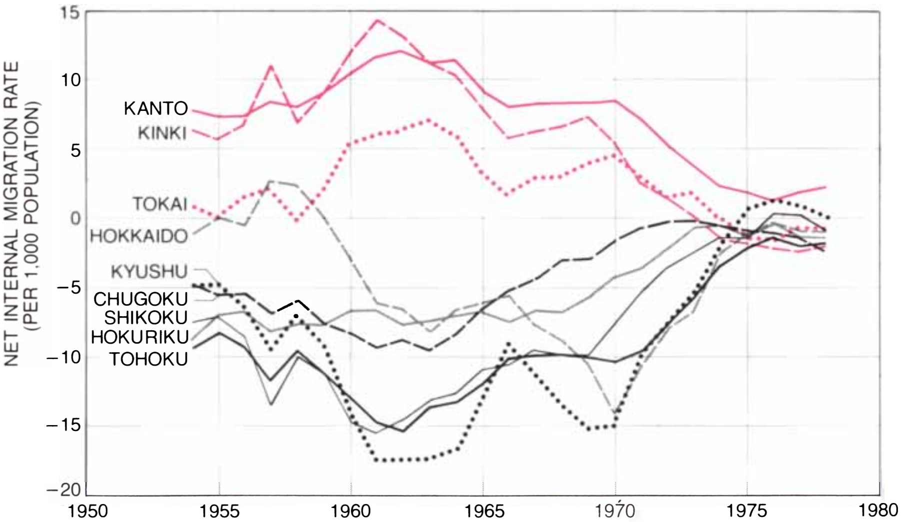
The southern Italian region called the Mezzogiorno, which makes up much of the nation's periphery, has difficult topography and an uncertain water supply. In Japan the drawbacks of the peripheral regions are extreme. There is a singular lack of level ground outside the central part of the island of Honshu, which includes all the major Japanese cities. The only large tracts of available flat land are on Hokkaido, the northernmost island, which has a severe climate with quite cold winters.

As I noted above, the economic advantages of setting up an industrial or service enterprise in a core region have largely been neutralized by economic and demographic growth. There are, however, still some disadvantages to being at a distance from the main concentrations of industry and population. When such disadvantages are combined with difficult terrain or climate, rapid growth in the peripheral region is apparently precluded. The only exception to this pattern in the third group of nations is New Zealand, where the core consists of the northern half of North Island and the periphery includes the remainder of North Island and South Island. South Island has no serious geographic deficiencies. The major industrial concentration around Auckland on North Island, however, is small enough so that the economies of scale within the country remain substantial.

Since the peripheral regions of Mediterranean Europe, Japan and the Nordic countries have such inferior endowments, the question arises of why the rate of migration to the core declined sharply in these countries in the 1970's. One reason is that the waning of economies of scale was accompanied by government policies intended to prevent further loss of population from the periphery. In Norway, for example, the government has carried out a program with the explicit aim of making the northern, peripheral areas more attractive to individuals and businesses. The infrastructure has been augmented at public expense. Hard-surface all-weath-



CORE REGION OF JAPAN is shown in dark color. To approximate the Japanese core the author combined the regions of Kanto, Kinki and Tokai, which are shown in light color. The three regions are all on the island of Honshu; they include the major cities of Tokyo, Nagoya and Osaka. The core of Japan has a population of about 65 million. One reason the population density is so high in the core is that almost all the flat land for building in Japan is in the central part of Honshu on the east coast. The only substantial areas of available flat land in the periphery are on the northern island of Hokkaido, which has a severe climate with harsh winters.



MIGRATION BETWEEN REGIONS OF JAPAN is apparently constrained by geographic factors. The core regions of Kanto, Kinki and Tokai are represented by the three upper curves. The six lower curves are for the areas that constitute the periphery. As in the outlying countries of western Europe, migration into the core reached a peak in the 1960's and then declined sharply in the 1970's. There has not, however, been a net outflow from the core region of Japan by migration. The main reason is that the geographic deficiencies of the peripheral regions make them unsuitable for large-scale industrial development and urban settlement.

er roads have been constructed, schools and hospitals have been built and high-speed boats have been put into service to link remote coastal villages. In addition subsidies have been given to businesses that invest capital in the north.

Such "deconcentration" policies have been put into effect in many of the 22 countries of my sample. In North America and northwestern Europe the policies have merely served to increase the attractiveness of the peripheral regions. In the countries of the third group, on the other hand, deconcentration policies have helped to compensate for deficiencies in the peripheral region. The balance of migrational flows in these countries remains delicate. In some of them (including Britain, Italy and Japan) there have recently been increases in the rate of migration into the core, although the increases have not brought the rate to the level of the 1950's and 1960's. I doubt there will ever be a substantial movement toward the periphery in the developed world except for North America and the countries of continental northwestern Europe. It seems likely that in the other countries there will at most be a balance of flows.

Strong deconcentration policies have also been adopted in eastern Europe. The policies have not been as effective as they have in western Europe, however, because the eastern countries are at a lower level of economic development. The economies of scale are still considerable; furthermore, too little surplus capital has been accumulated to enable the government to offer large subsidies in the periphery. As a result in Czechoslovakia, East Germany, Hungary and Poland there is a fairly constant net rate of migration into the large urban centers. Nevertheless, the rate is lower than the rates recorded in western Europe when core regions there were expanding rapidly.

In the developing world the economies of scale are even more of an inducement to concentration than they are in eastern Europe; they correspond to the economies that prevailed in the developed world in a much earlier phase of industrialization. Furthermore, although deconcentration policies have been adopted in some parts of the developing world, they are quite weak. Accordingly the net migration into the core regions is very large. South Korea and Taiwan are the only parts of the Third World for which annual statistics on internal migration are available. In both places the flow into the core is huge and shows no sign of abating. The rate of migration into the Seoul area, the core of South Korea, is between 3 and 4 percent per year; the rate for Taipei, the core of Taiwan, is between 1 and 2 percent. These rates are considerably higher than those in Europe or the U.S. at a comparable stage of development; indeed, they are among the highest net migration rates into core regions that have ever been recorded. Recent census data from other developing countries, including Brazil, India, Mexico and Turkey, suggest that migration into the large cities there is also undiminished.

A high level of economic development appears to be necessary before demographic deconcentration can begin. It should be noted that the level of economic development and the rate of migration from the core do not bear a direct relation to the population of the largest urban areas. The flow of people toward the core in Iceland, Norway, Italy and Japan decreased abruptly in about 1970, and in each country the net migration rate is now approaching zero. Consider the disparity in size among the cores of these countries: southwestern Iceland has a population of 150,000, eastern Norway two million, northwestern Italy 15 million and the Tokaido area in Japan 65 million.

Although the beginning of the decline in net migration bears a stronger relation to the level of economic development than it does to the population of the core, it does appear that the core must be a certain absolute size for the decline to be converted into a significant loss of population. Furthermore, as we have seen, the periphery must offer suitable sites for industry. In the absence of one of these conditions there is no significant net outflow. In Japan, where the core has a large population but the periphery is geographically deficient, there is no net outward flow; in New Zealand, where the periphery is geographically advantageous but the core is small, there is no outward flow. In France, where both conditions are met, there is a migrational flow from the Paris basin to the periphery.

The reversal of internal migration in the developed countries is a phenomenon that has so far been little studied. Any hypothesis about its causes must therefore be somewhat speculative. Although the reversal is not fully understood, it could have a strong effect on the political future of the developed world. In the U.S. it has already caused a shift in the balance of political power. Seats in the House of Representatives are apportioned on the basis of the census. After the 1980 census, for the first time in this century, the South and the West have more seats in the House than the states of the core. Shifts in political power in other developed countries will probably be less dramatic than the one in the U.S. Nevertheless, the current reversal of demographic patterns undoubtedly carries with it significant social and political consequences that will become increasingly apparent in the rest of this decade and in the decades that follow.

EASTERN EUROPE AND THE THIRD WORLD show migration patterns quite different from those of the more developed countries. In Czechoslovakia, East Germany, Hungary and Poland there is a fairly small but consistent flow of people into the core in spite of government policies aimed at preventing further migration from the periphery to the core. In South Korea and Taiwan economic development is still under way and the rate of migration into the core is extremely high. The Seoul region gains migrants equal to between 3 and 4 percent of its population per year; the Taipei area gains almost 2 percent per year. These rates are among the highest ever recorded, reflecting the fact that economies of scale in the Third World are still substantial. Because of a change in the way statistics are kept the data concerning internal migration between regions of Taiwan in 1969 are not comparable to the data shown and so have been omitted.

Radar Images of the Earth from Space

Orbiting radar systems capable of synthesizing images of the earth's surface from backscattered microwaves are providing new information about surface features

by Charles Elachi

Most images of the earth from space have been made in much the same way as ordinary photographs are: by collecting, focusing and recording reflected solar radiation. Other remote-sensing techniques rely on thermal or microwave radiation emitted from the earth's surface. A fundamentally different technique for making satellite observations has now been introduced. An orbiting radar system directs a beam of microwaves obliquely onto the earth; the radar then detects the backscattered radiation and synthesizes an image from it. Passive high-resolution imaging devices generally work with visible light or with radiation in the adjacent infrared or ultraviolet regions of the electromagnetic spectrum. Active space-borne radar extends the detailed study of the earth's surface from orbiting spacecraft into the microwave region of the spectrum, thereby gathering information about surface properties that until now were undetectable.

Because an active radar system provides its own illumination it is not dependent on light from the sun; hence it can operate at any time of the day or night. Because clouds, fog and precipitation have little effect on microwaves such a system can obtain images in all kinds of weather. This uninterrupted imaging capability is crucial to the observation of dynamic phenomena such as ocean currents, migrating ice floes and changing patterns of vegetation.

The brightness of a given point in the radar image depends on the intensity of the microwave energy scattered back to the radar receiver from the corresponding point on the earth's surface. The intensity of the backscatter depends in turn on both the physical properties of the surface (such as its slope, roughness and vegetation cover) and its electrical properties (chiefly its conductivity, which is related to such factors as the porosity of the soil and its water content). In the visible and near-infrared regions of the spectrum the earth's reflectivity is determined for the most part by its chemical composition, whereas at longer, thermal-infrared wavelengths the reflectivity is a function primarily of the heat capacity of the ground. In short, observations with a combination of sensors are needed for a complete description of the face of the earth.

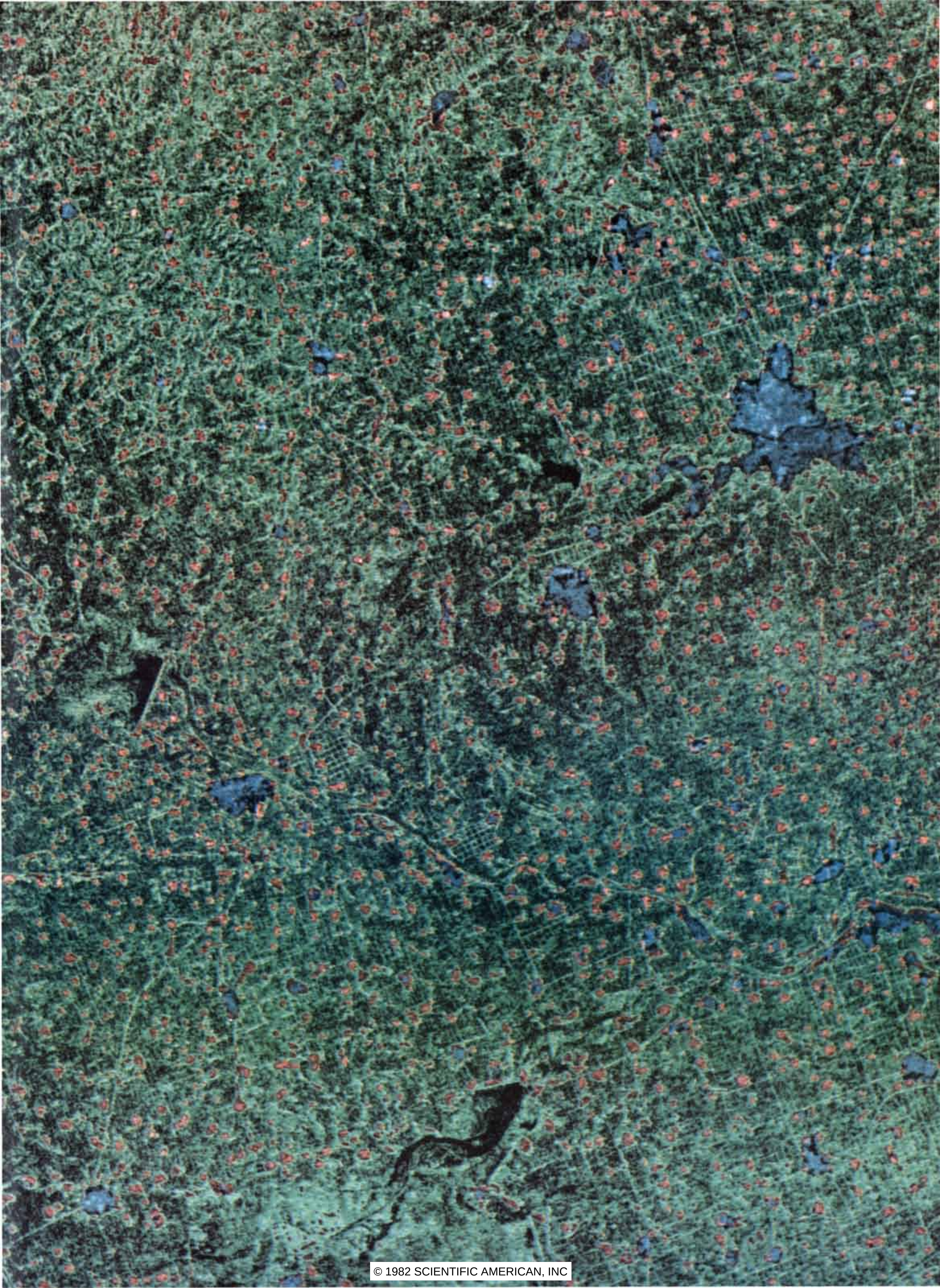
So far two imaging radar systems have been operated in earth orbit. The more recent one was on board the space shuttle *Columbia* on its second flight, in November, 1981. It was called *SIR-A*, for *Shuttle Imaging Radar-A*, and it made strikingly detailed pictures of physiographic features from around the globe. An earlier instrument was flown on the *Seasat* spacecraft in 1978. Both radars were developed at the Jet Propulsion Laboratory of the California Institute of Technology.

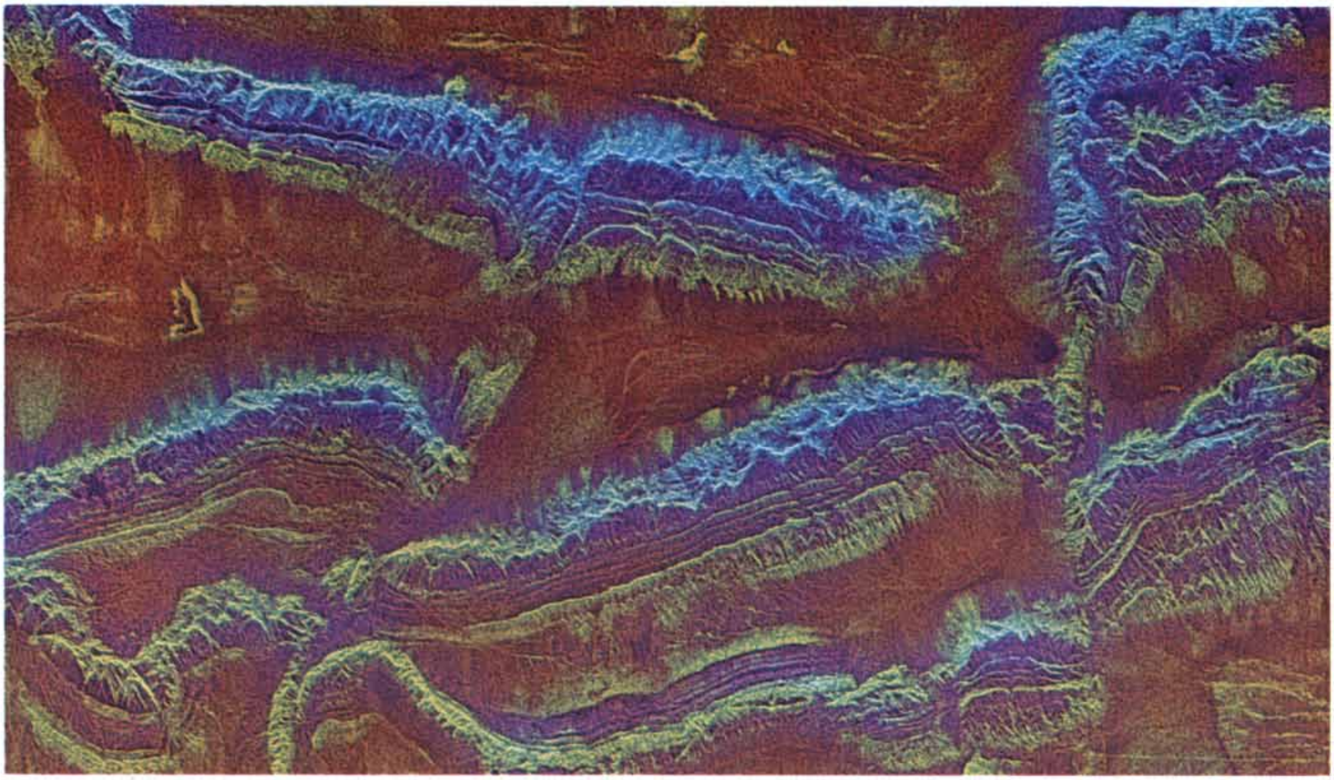
In an optical or an infrared imaging system the energy emitted by or reflected from a surface is intercepted by an aperture and is focused on a detecting element (or an array of elements). The angular resolution of the sensor is determined by the ratio of the observing wavelength to the diameter of the aperture; the spatial resolution is equal to the angular resolution multiplied by the distance between the sensor and the surface. The resolution is diminished as the altitude of the sensor increases, as the observing wavelength increases or as the diameter of the aperture decreases. Because of the very short wavelength of visible and infrared radiation high-resolution imagery can be achieved even from an orbital altitude of several hundred kilometers with an aperture of reasonable size.

In the microwave region of the spectrum the wavelength is several orders of magnitude greater; both the *SIR-A* and the *Seasat* radars had an operating wavelength of about 24 centimeters, about a million times the wavelength of visible light. For a radar satellite to attain the same spatial resolution as an optical one from the same altitude the aperture must be increased by a like factor. To obtain a ground resolution of 25 meters, say, a conventional radar imaging system at an altitude of 250 kilometers and operating at a wavelength of 20 centimeters would need an aperture of two kilometers! Clearly some other technique is needed to generate high-resolution images with a remote radar sensor.

The solution, developed originally for side-looking airborne radar systems (SLAR), is called synthetic-aperture radar. In this approach a comparatively small radar antenna is made to function as a very large (albeit long and thin) one by taking advantage of the antenna's motion along a well-defined path. A large real antenna (or an array of antennas) transmits signals and picks up their echoes over the entire antenna surface simultaneously. The echoes from all parts of the antenna surface are combined as they arrive in the radar's waveguide network before being detected by

INTRICATE LAND-USE PATTERN is delineated in this false-color radar image of a rural area of Hopeh Province in northeastern China. The image was recorded by the *Shuttle Imaging Radar-A*, or *SIR-A*, system from an orbital altitude of about 250 kilometers. The color processing was done at the Jet Propulsion Laboratory of the California Institute of Technology. The colors bear no relation to the natural colors of the scene; they were assigned solely on the basis of the intensity of the backscattered microwave radiation detected by the radar antenna. The red spots correspond to villages. The dark green areas are cultivated fields and the light green lines are roads and irrigation canals. The gray and black shapes are lakes and ponds, some of them formed by the damming of watercourses. The principal crop of the area is wheat.



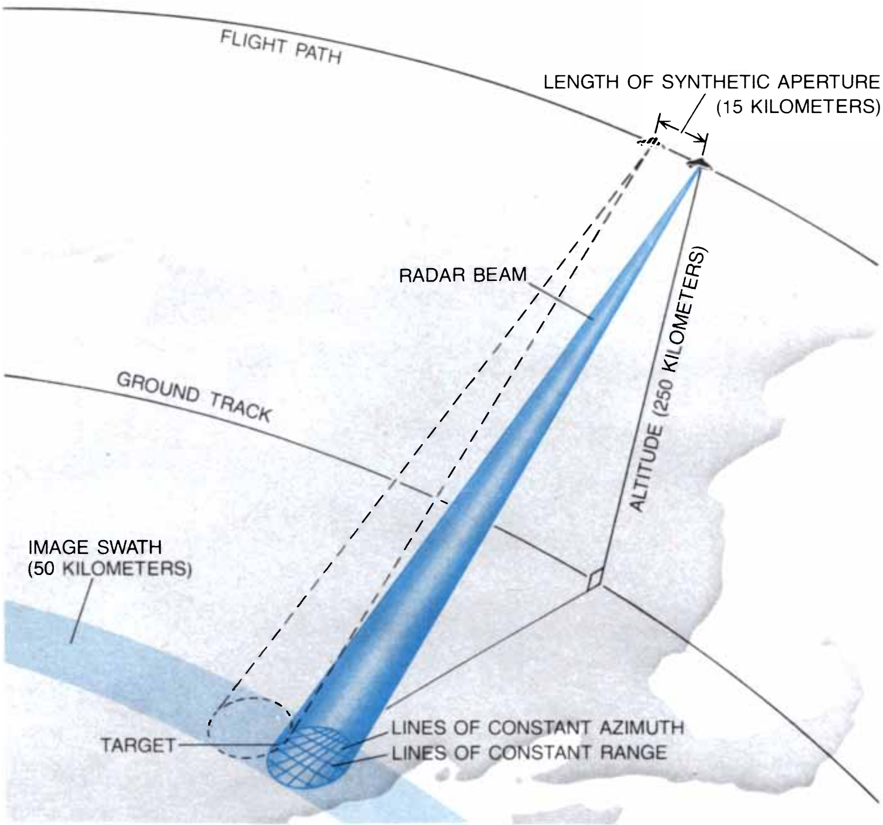


GROSS GEOLOGIC FEATURES predominate in this false-color *SIR-A* image of an arid, mountainous region of Sinkiang Province in northwestern China. The mountain ranges were created by the uplifting of sedimentary rocks; displacements along the ranges mark major fault zones. Alluvial fans formed by erosion along the flanks of the mountains are very rough at the scale of the radar wavelength (24 centimeters) and hence return a strong backscattered signal. Playas, or desert basins, between the ranges consist of finer, smoother material that yields a comparatively weak radar return. Folding and stratification of the rocks are also visible in the mountainous areas.

SUBTLE GEOLOGIC FEATURES appear in this radar image of a heavily forested region of southern Mexico near the border with Guatemala. The image was recorded by the radar system carried into orbit by the *Seasat* spacecraft in 1978. Special processing techniques were applied to the data to modulate the color of the image in relation to low-frequency (or large-scale) spatial variations and the brightness of the image in relation to high-frequency (or small-scale) ones. In this way inconspicuous structures such as faults can be enhanced. The confluence of the Lacantum River (*top*) and the Salinas River (*bottom*) is just off the picture frame to the northwest (*right*).

the receiver. The reason the resolution improves as the aperture increases is not simply that a larger antenna can collect a stronger signal. What is important is that waves are scattered from each point on the target surface to various areas of the antenna; as the scattered waves are combined they interfere with one another according to their amplitude and phase. The interference pattern encodes detailed information about the surface.

A synthetic-aperture radar also resolves fine details by extracting information from waves received over a large area. The difference is that the waves are not detected simultaneously in all parts of the "synthetic" antenna. Instead as the small antenna moves along its track the signals received at each position are recorded, and they are combined after the fact by a data-processing system. To establish a reference by which the amplitude and phase of the echoes can be measured a very stable signal is combined with the echoes as they are received by the sensor. A similar technique is used in radio astronomy to form a very-long-baseline interferometer by combining the signals from an array of widely separated radio telescopes.



SPACE-BORNE IMAGING RADAR OPERATES on the synthetic-aperture principle, as is shown in this schematic diagram. As the side-looking radar system travels along its flight path it transmits a beam of coherent microwave pulses obliquely at the earth's surface. The backscattered signals received by the radar antenna are recorded. Signals detected at various points along the orbital track are later combined by a data-processing system to form a two-dimensional image of the target area. In effect the moving radar antenna functions as a single elongated antenna (or as a long array of small antennas); the maximum length of the resulting synthetic aperture is the distance along the track for which a given target is within the illuminating beam of the antenna. Each point on the surface is characterized by two quantities: its range, which is a function of the delay between the transmission of a pulse and the reception of the echo, and its azimuth, which is determined by measuring the change in frequency caused by the relative motion of the spacecraft and the target (the Doppler effect). The image is assembled by analyzing all the delay and Doppler-shift information encoded in the collected echoes.

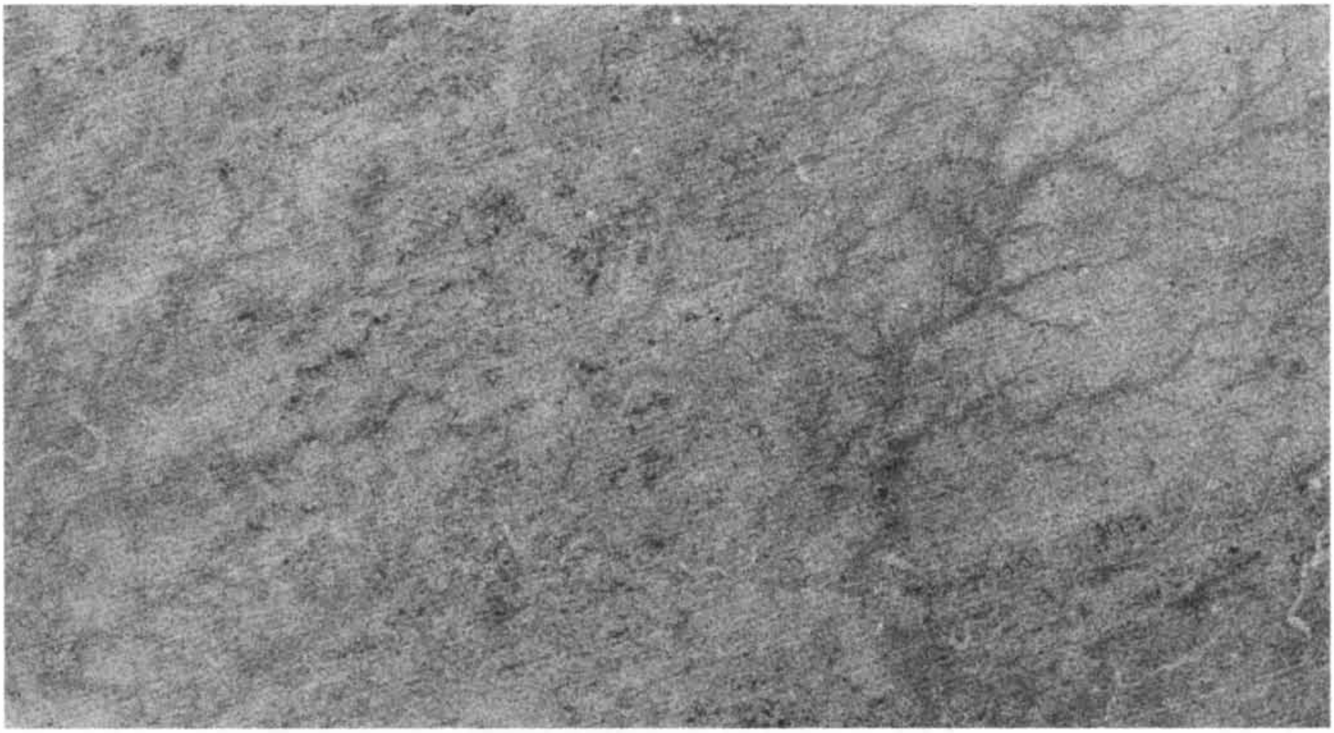
In practice an aircraft or a spacecraft carries the small real antenna along the track, and the long antenna array is synthesized by combining the echoes received at different positions along the track. The maximum length of the synthetic aperture is the distance along the track for which a given target is within the illuminating beam of the antenna. As the altitude of the antenna increases, the maximum length of the synthetic aperture increases proportionately, so that the attainable spatial resolution remains constant [see "Side-looking Airborne Radar," by Homer Jensen, L. C. Graham, Leonard J. Porcello and Emmett N. Leith; SCIENTIFIC AMERICAN, October, 1977].

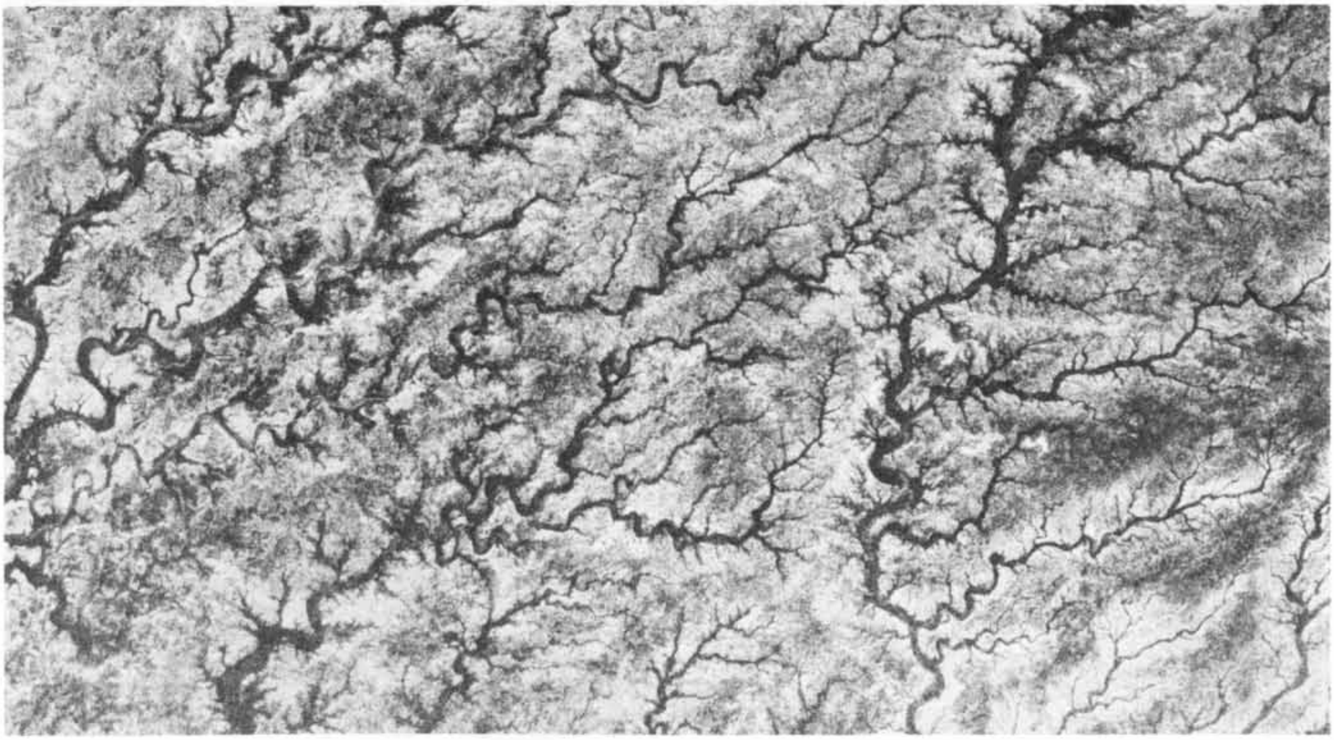
Basic to the operation of any synthetic-aperture radar system is the fact that the wave properties of the illuminating beam, unlike those of sunlight, can be specified and controlled. The illumination consists of a series of coherent microwave pulses at a precise, stable frequency. The delay between the transmission of a pulse and the reception of its echo gives the range of a target. Signals from points on the surface that differ in range can therefore be separated according to their time of arrival at the antenna. For any given position of the spacecraft, however, there are many points with the same range; they form a circle centered on the point directly under the satellite. Signals from different points with the same range can be distinguished by measuring the Doppler shift of the echoes: the change in frequency caused by the relative motion of the spacecraft and the target. Only the component of motion parallel to the direction of the microwave beam contributes to the shift; hence the echo from a point perpendicular to the flight path has a Doppler shift of zero. Points ahead of the perpendicular are shifted to higher frequencies, those behind the perpendicular to lower frequencies. The combined delay and Doppler-shift data in the echoes, recorded as the sensor flies over a given area, are processed to isolate the energy returned from each resolution element on the surface. Thus by analyzing the delay and Doppler-shift information in the echoes one can map the received energy into a two-dimensional image that represents the scattered energy on a point-by-point basis.

The resolution of a synthetic-aperture radar is determined by the ability of the sensor to accurately measure minute differences in delay and Doppler shift resulting from adjacent surface elements. The accuracy of these measurements does not depend on the distance from the sensor to the surface. Thus as long as the returned signal is sufficiently above the noise level the resolution attainable with this kind of imaging system is essentially independent of its altitude. Both the *SIR-A* and the *Seasat* radars provided images having a ground resolution of 25 meters or so with an antenna 10 meters long at a wavelength of 24 centimeters. This resolution exceeds by a factor of three the resolution achieved with the early Landsat sensors, which relied on reflected visible and near-infrared radiation from the sun.

To analyze the full delay and Doppler-shift history of the echoes recorded while a single resolution element is viewed by the sensor requires a large number of calculations and data manipulations. In the case of the *Seasat* radar some 1,000 complex operations were needed to synthesize the long aperture and to determine the brightness of a single pixel, or picture element, 25 meters on a side. The satellite moved at about 7.5 kilometers per second and the sensor covered a swath 100 kilometers wide on the ground, so that approximately a billion operations were needed to generate a high-resolution image from the information recorded in one second. In addition the data processor had to take into account the Doppler shifts caused by the earth's rotation and the distortions caused by slight variations in the altitude and attitude of the sensor.

The large data-processing demand of a space-borne synthetic-aperture radar has been a major challenge to the development of such systems. The CRAY-1, one of the fastest computers currently available, is capable of executing about 100 million operations per second, which is an order of magnitude slower than the rate needed for the real-time processing of data from the *SIR-A* or the *Seasat* radar. Two approaches have been developed to handle this prodigious data-processing chore, one of them optical and the other digital.

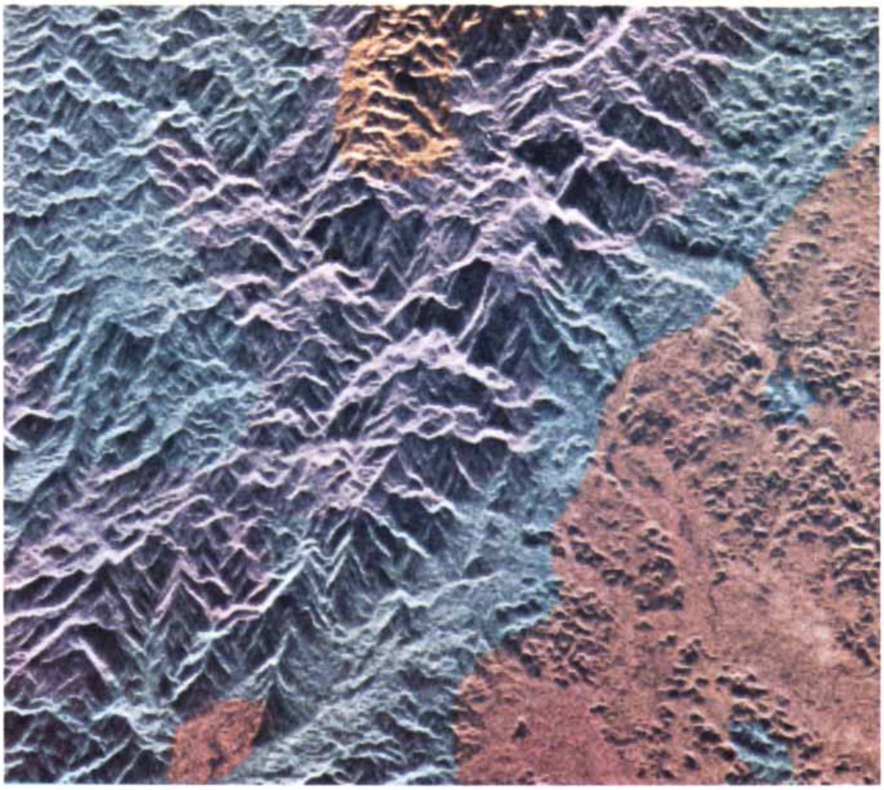




DRAINAGE CHANNELS in a rocky desert along the border between Iraq and Saudi Arabia are barely visible in a Landsat image (*top*) but are sharply defined in a *SIR-A* radar image of the same area (*bottom*). Intermittent running water cuts the narrow valleys called wadis in the exposed rock. The wadis are partially filled with windblown sand, which returns a much weaker signal to the radar than the surrounding rock. The strong contrast in the radar image makes it easier to trace the drainage pattern there than in the Landsat image.

When the echoes are optically recorded on a photographic emulsion, the return from a point target forms a characteristic set of concentric rings similar to the Fresnel-zone pattern commonly encountered in optics. A plane optical wave falling on such a pattern can be focused to a point that is an image of the target. This simple procedure (which can be thought of as a two-dimensional analogue of holography) is the basis of all optical techniques for processing the data from a synthetic-aperture radar. Optical processors operating on this principle were first developed in the 1950's and the early 1960's by workers at the University of Michigan and the Goodyear Aerospace Corporation for processing the data from airborne synthetic-aperture radars. Optical systems were later adapted at the Jet Propulsion Laboratory for processing the data from the *SIR-A* and the *Seasat* radars.

The second approach to the data-processing problem depends entirely on the digital computer. The large number of calculations required have limited the present capability to operations that make no attempt to keep up with the stream of data as it issues from the sensor. The fastest available digital processor for space-borne imaging radars has a "throughput ratio" of one to 500, that is, the data collected in one second require 500 seconds of processing. The processor was developed at the Jet Propulsion Laboratory by a team headed by Chialin Wu. Slower processors have been developed in Britain, Canada, Germany and Japan. A processor that can match the data rate of the sensor is now under development at the Jet Propulsion Laboratory. It is scheduled for completion in 1985.



VARIATIONS IN TEXTURE were analyzed mathematically in order to assign false colors to a *SIR-A* image of a mountainous region in Belize. Differences in the texture of various parts of the image correspond to spatial variations in the landforms. The technique is being investigated by Thomas G. Farr of the author's group as a way of mapping areas by types of rock.

Radar images of the earth from space are currently finding application in a number of areas in geology, planetology, oceanography and the study of renewable resources. One area in which the exploitation of radar data is particularly advanced is in the mapping of landforms. Many surface and near-surface geologic features such as faults, domes, rock outcrops and the like are associated with recognizable variations in the appearance of the surface, specifically in its topography, roughness or vegetation cover. Erosional processes also generate recognizable features and patterns. Because the microwave backscatter is very sensitive to changes in the physical properties of the surface these features and patterns are clearly observed and in some cases enhanced in the radar imagery.

At any wavelength the observation of topographic details is strongly dependent on the illumination geometry. Details are best observed when the illumination is almost perpendicular to the direction of the topographic trend. In the case of visible and near-infrared sensors the illumination direction is determined by the position of the sun and varies mainly in the east-west direction. In the case of radar sensors the illumination direction and angle of incidence can be selected and controlled, thereby providing more flexibility. Changes in slope of a few degrees can change the radar backscatter by a factor of two or more, and so radar sensors are ideal for detecting subtle structural features that influence the topography. This advantage of the radar images is particularly helpful in studying heavily forested regions, such as those in the Tropics. To detect subtle topographic features special image-processing techniques have been devised to enhance both the low-frequency (or large-scale) spatial variations in the radar images and the high-frequency (or small-scale) ones.

Erosional processes work on many scales. Surface roughness on the scale of a few centimeters to a few meters is dependent on the composition of the surface and on the particular erosional process at work. Roughness in this range of scales has only a limited effect on the optical reflectivity of the terrain, but it is the dominant factor determining the radar backscatter. This effect has proved to be particularly useful in mapping very arid regions where "desert varnish" and thin sheets of sand tend to subdue the reflectivity and to reduce spectral variations in the visible and near-infrared parts of the spectrum.

Because of the long wavelength of the radiation exploited by radar sensors one would expect some penetration below the surface. The depth of penetration is usually proportional to the wavelength of the signal and is strongly dependent on the surface moisture. In the very arid regions of the world subsurface penetration of a few meters is possible. While analyzing *SIR-A* data acquired over the eastern Sahara in Egypt, workers at the U.S. Geological Survey and the Jet Propulsion Laboratory recently noted that many large-scale features seen in the radar images are not visible on Landsat images or on the ground. These seem to be subsurface features that are covered by a layer of sand a few meters thick. The presence of such features has long been suspected by geologists engaged in investigating the geologic history of the Sahara. They include river valleys (some as wide as the present Nile valley), river terraces, desert basins and bedrock structures. The ground-penetrating capability of the radar sensors, which was recently verified by ground investigations, promises to have far-reaching implications in archaeological, geological and hydrological exploration of arid regions.

In the humid Tropics the vegetation

canopy can also be penetrated to a limited extent by microwave signals. *SIR-A* images of southern Borneo seem to delineate swamp areas that are completely covered by vegetation. Comparable results were also obtained by workers at the University of Arkansas in analyzing *Seasat* radar images of central Arkansas.

The discrimination and identification of different types of rock by remote sensors can be best done by analyzing the spectral "signature" of the visible and infrared radiation reflected or emitted. Recent developments should extend such two-dimensional spectroscopic imaging to a large number of visible and infrared spectral bands that are diagnostic of the composition of the surface rock. In this area radar images can provide complementary information that can indirectly contribute to lithologic mapping. Surface roughness and small-scale topographic texture, which have an important effect on the radar echo, depend on the type of rock present. Thus radar information is helpful in discriminating, although not in identifying, rock types. For example, once a lithologic zone has been identified by other means, radar mapping can help to define its boundary.

Work done by my group at the Jet Propulsion Laboratory has shown that the addition of radar-image data to the data supplied by the Landsat multispectral scanner improves the rock-classification capability. The importance of the radar data is even greater in vegetated areas where a multispectral image of the surface cannot be made. In these areas the only viable approach to the remote classification of rocks is to exploit variations in surface texture and drainage density, two properties that are usually related to the rock types. A number of image-processing techniques are being tested at the Jet Propulsion Laboratory and at the University of Kansas to classify areas based on the texture observed in the radar images. The attempts have been particularly successful in the study of heavily vegetated regions.

The presence of vegetation or manmade structures has an appreciable effect on the radar return. Vegetation tends to scatter radar waves strongly because of its high moisture content and because of the dense array of reflecting surfaces in the forest canopy. Cultivated fields and clear-cut forests are easily delineated in radar images. Work is now being done at the University of Kansas on the problem of relating the strength of the radar return to the nature of the vegetation, its growth stage and its health. So far attempts to correlate ground measurements with radar images have given encouraging results.

SIMULATED RADAR IMAGE of Mount Shasta in northern California was prepared by Michael Kobrick of the Jet Propulsion Laboratory in the course of investigating the feasibility of gathering three-dimensional information about the earth's surface by means of a spaceborne radar interferometer. In such a system the phase difference between the microwave echoes received by two antennas mounted on the same spacecraft would be measured on a point-by-point basis to generate a topographic image. Here the topographic data were actually obtained first by conventional means and then processed to simulate the digital output of an orbiting radar interferometer. The multicolored topographic contours derived from the resulting stream of digital information correspond to lines of constant height above sea level.

Manmade structures strongly reflect radar signals primarily because flat perpendicular surfaces tend to form corner reflectors that return a major part of the incident energy and because metallic structures act as antennas that strongly reradiate the incident energy. Many manmade structures are visible in the *Seasat* and *SIR-A* images even though they are smaller than a resolution element. Among the frequently observed features are railroad tracks, country roads, power-line towers, bridges, oil-drilling platforms and ocean vessels. The feasibility of combining radar images and Landsat images is being tested to improve the capability of remotely monitoring urban land-use patterns on a large scale.

All imaging sensors, including radar instruments, yield a two-dimensional representation of a scene. Hence the topography of the surface cannot be fully inferred from a single image. A stereoscopic pair of images made from different positions is needed to determine the height of the individual pixels and to generate a contour map. The process of topographic mapping with stereoscopic pairs could be employed with radar images, and indeed it is being investigated. The method is tedious, however, particularly for large-scale mapping.

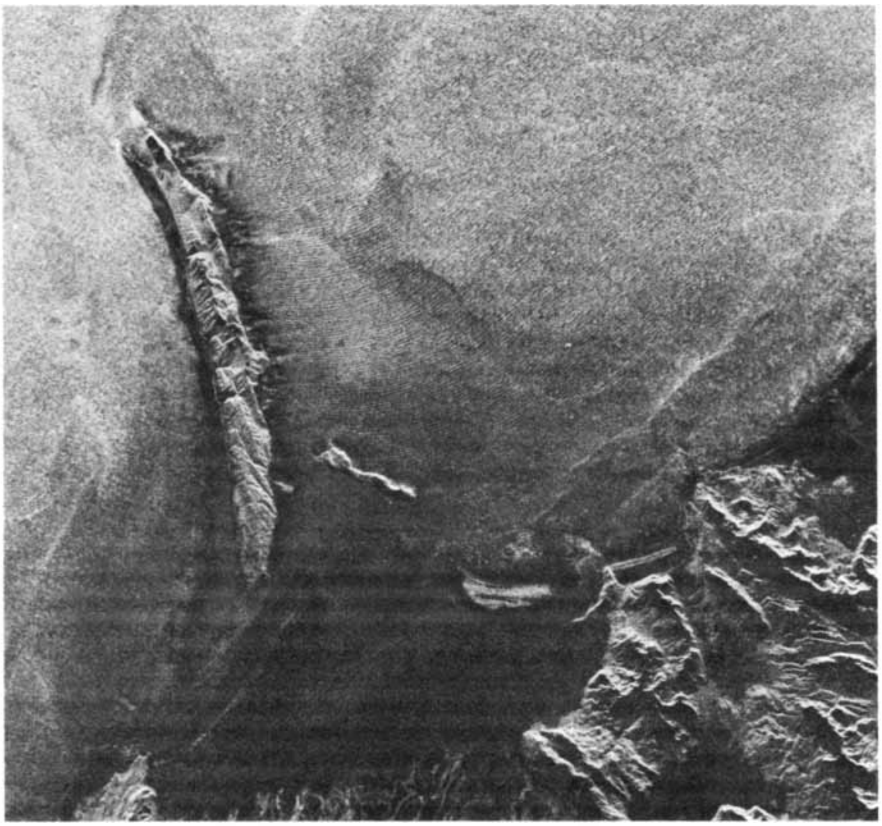
The fact that the radar sensor has its own controlled illumination led L. C. Graham of Goodyear Aerospace to introduce an interferometric technique in conjunction with the synthetic-aperture technique to gather three-dimensional information about the surface. His approach calls for two separate antennas, both mounted on the same aircraft. Only one antenna illuminates the surface but both antennas collect the returned signal. The two receivers rely on a common reference source to compare the phases of the two received echoes. The phase information enables one to measure directly the height of each pixel in the resulting image and eliminates the need for stereoscopic analysis. Recent work and a detailed concept simulation by workers at the Jet Propulsion Laboratory indicate that the approach is feasible from space.

Microwave signals do not penetrate to any significant depth in water. On the other hand, the intensity of the radar backscatter is highly sensitive to surface capillary waves and small gravity waves, just as it is to surface roughness on land. In principle, therefore, any ocean feature that alters the roughness of the surface can be detected by satellite radar. It turns out that many ocean features do influence the surface roughness. Swells generate a periodic modulation of the intensity of the smaller waves, and so the pattern of swells is commonly observed in radar images. The velocity of currents at the surface also modulates the roughness. The current velocity in turn is modulated by the bottom topography in shallow areas. As a result coastal bottom features have been observed in a number of radar images even though no microwaves reach the bottom.

Internal waves propagate along layered inhomogeneities in the ocean. The water circulation associated with the waves modulates the surface roughness in a well-defined, recognizable spatial pattern. The images made with *Seasat* and *SIR-A* showed that internal waves are much commoner than had been thought. Eddies, warm-water rings, fronts, suspended sediments and near-surface wind cells also affect the surface roughness and are observed in radar images. The phenomena can be monitored regardless of weather conditions, cloud cover or time of day or night. Thus satellite radar can provide repetitive coverage for studying changes in the surface features or for tracking their movements.

In addition to the effect of surface roughness on the intensity of the radar return from the ocean, surface motion affects the frequency content of the returned signal as a result of the Doppler effect. Workers at the Jet Propulsion Laboratory and the Environmental Research Institute of Michigan are investigating the exploitation of this small Doppler shift to map the velocity of ocean currents.

In the polar oceans ice floes, ice ridges and open-water channels all have a characteristic radar return that can be distinguished in the radar image. Repetitive coverage with the *Seasat* synthetic-aperture radar over the Beaufort Sea in the summer of 1978 enabled Benjamin Holt of the Jet Propulsion Laboratory to track an ice feature over a distance of more than 160 kilometers. Such an approach should make it possible to monitor the long-term motion of the polar ice, which is driven by polar currents and is thought to make one complete revolution about the pole in two years. In addition the continuous monitoring of ice floes is necessary for the planning of ship routes and the positioning of drilling platforms in the polar seas. This capability has led the Canadian government to plan an ice-observation satellite with a synthetic-aperture radar system for launching in the late 1980's. The delineation of the ice cover and its extent is also of particular interest in determining the heat flow from the ocean to the atmosphere, a key variable in models of the world climate.



OCEAN SWELLS with a wavelength of about 200 meters are apparent in a *Seasat* radar image of the waters around Kayak Island in southern Alaska. The waves are refracted and diffracted as they interact with the coast of the island and with the shallow bottom of Controller Bay.

Until recently the analysis of radar imagery was mainly qualitative. It was based on delineating features and patterns, measuring their size and studying any association of patterns to infer some information about the surface. In the past few years a start has been made on developing quantitative techniques that will provide a better understanding of the radar signature of different surface features. Calibrated radar images could yield further information about surface roughness and soil moisture, and mathematical techniques could be applied to the classification of textures. Quantitative data from both radar and multispectral images could aid in the identification of surface features. A series of radar images made with beams that differ in their plane of polarization could make possible separate measurements of surface roughness and dielectric constant (a fundamental electrical property). Images made with multiple frequencies could also be employed to measure the range of surface roughness. Many techniques originally developed for the interpretation of Landsat images are being applied to the radar images, thus enabling rapid progress to be made in the development of the radar methods.

Programs are under way for the development of more sophisticated radar observation systems. The emphasis in the U.S. is on multipurpose radar sensors for research, to be carried into orbit by the space shuttle. The next step in the U.S. program is the 1984 flight of *SIR-B,* which will generate images with a wide variety of illumination geometries. The emphasis in Canada, Europe and Japan is more on the development of satellite systems for long-term observation.

The radar sensor is the only tool available for observing the surface of some other bodies in the solar system. Because of the continuous global cloud cover of Venus and of Titan (the largest moon of Saturn) little is known about their surface. During the recent Pioneer Venus Orbiter Mission a radar mapper with a resolution of about 80 kilometers provided the first look at many of the major surface features of Venus. A planned (but not yet approved) Venus Radar Mapper Mission may someday yield a much more detailed picture of the surface. In the case of Titan knowledge of the surface is nil and is the subject of much speculation. An orbital imaging radar is the only option available for constructing a global picture of the surface of this remote world.

The Development of Maps and Stripes in the Brain

In the human brain nerve cells form maps of their relations with the external world, and the maps are divided into stripes. How the stripes form is explored by creating a frog with three eyes

by Martha Constantine-Paton and Margaret I. Law

The brain of a vertebrate animal is the most complex structure in any living organism. The versatility and analytical abilities of that structure are suggested under the microscope by the appearance of individual neurons, or nerve cells. Each such cell appears to be different from its neighbors in its elaborate form and its links with other neurons by means of synapses at the tips of its axon, or nerve fiber. There is nonetheless a remarkable consistency imposed on this diversity. As more is learned about the patterns of connectivity in various parts of the brain, principles of organization begin to emerge, raising the hope that the types of neuronal interactions underlying the apparent complexity will turn out to be manageably small in number.

One such principle of organization is mapping. The axons that project from neurons in one region of the brain to neurons in another region generally reproduce neighborhood relations. As a result if two neurons are neighbors in the first region, their synapses will form on the same cell or on neighboring cells in the second region: the target population. This regularity in axonal projections was initially detected in the 19th century. It has now been found in all the projections through which sensory signals reach the cerebral cortex, in the projections through which one area of the cerebral cortex is connected to another and in the projections through which the parts of the brain involved in the control of movement act on the muscles of the body.

A second principle of organization, much more recently recognized, is the partitioning of the regions of the brain that embody a map into periodic subdistricts. For example, work in the laboratory of Jon H. Kaas at Vanderbilt University has revealed a highly regular partitioning of the somatic sensory cortex: the part of the cerebral cortex that gets sensory data from muscles, joints and the skin. In the somatic sensory cortex the surface of the hand is represented by a map. Hence touching two points on the skin that are near each other elicits measurable electrical activity in groups of neurons that are neighbors in the cortex. In experiments with monkeys Kaas and his colleagues find that in the layer of the cortex where the entering axons make their synapses, designated Layer 4, the map is partitioned into bands. The bands separate sensory inputs from the hand according to the kinds of information the input carries. In some bands the neurons respond only to the onset of a touch; in the intervening bands the neurons have a more prolonged response. It is as if the map of the hand in the somatic sensory cortex of the monkey has been constructed by alternating stripes cut out of two distinct maps of the hand. One map (and one set of stripes) represents what are called rapidly adapting nerve endings in the skin; the other represents more slowly adapting nerve endings.

Edward G. Jones and his colleagues at the Washington University School of Medicine were among the first to demonstrate anatomically that such functional subdivisions arise because each subdivision receives particular axons. Jones and his colleagues employed a radiographic technique. They injected into the somatic sensory cortex on one side of the brain of a monkey a small quantity of amino acids labeled with tritium, the radioactive isotope of hydrogen. The amino acids were taken up by neurons in the cortex and transported down the axons projecting from some of those neurons to the somatic sensory cortex on the opposite side of the brain. There the labeled axons laid down a pattern of radioactivity that was detectable by coating slices of the tissue with a photographic emulsion sensitive to radioactivity.

The pattern of radioactivity in successive slices indicated that the axons terminate in a clearly delimited series of stripes. Thus inputs crossing from one side of the brain to the other as well as inputs carrying information from the skin terminate in stripes in the somatic sensory cortex. The partitioning of inputs to the somatic sensory cortex is not, however, the only example of striped patterns. There are many other examples. Stripes have been found in all sensory pathways, in many regions of the cerebral cortex and in regions of the brain as diverse as the superior colliculus, the cerebellum and the medulla oblongata.

Periodic synaptic zones that form functional stripes in a region of the brain that simultaneously embodies a map present a puzzle. Why are they there? Why should the brain establish an elaborate means of segregating various inputs when ultimately the inputs will converge to produce a unified representation? The two of us have done a series of experiments that suggests an answer to the question.

Our work focuses on the visual system, a set of projections that carry visual information from the retina to more central stations of the brain. These pathways have been studied intensively, and as a result more is known about the central nervous system's representation of the visual world than is known about the representation of any other sensory modality. Much of the work has been done, on the cat and the monkey, by David H. Hubel, Torsten N. Wiesel and their colleagues at the Harvard Medical School. Their results constitute a detailed analysis of the relation between topographic and functional organization. In the cat and the monkey the visual pathways convey information to the part of the cerebral cortex designated the visual cortex. The map there is binocular: it arises from axons delivering information from each of the animal's eyes. Hubel and Wiesel have found,

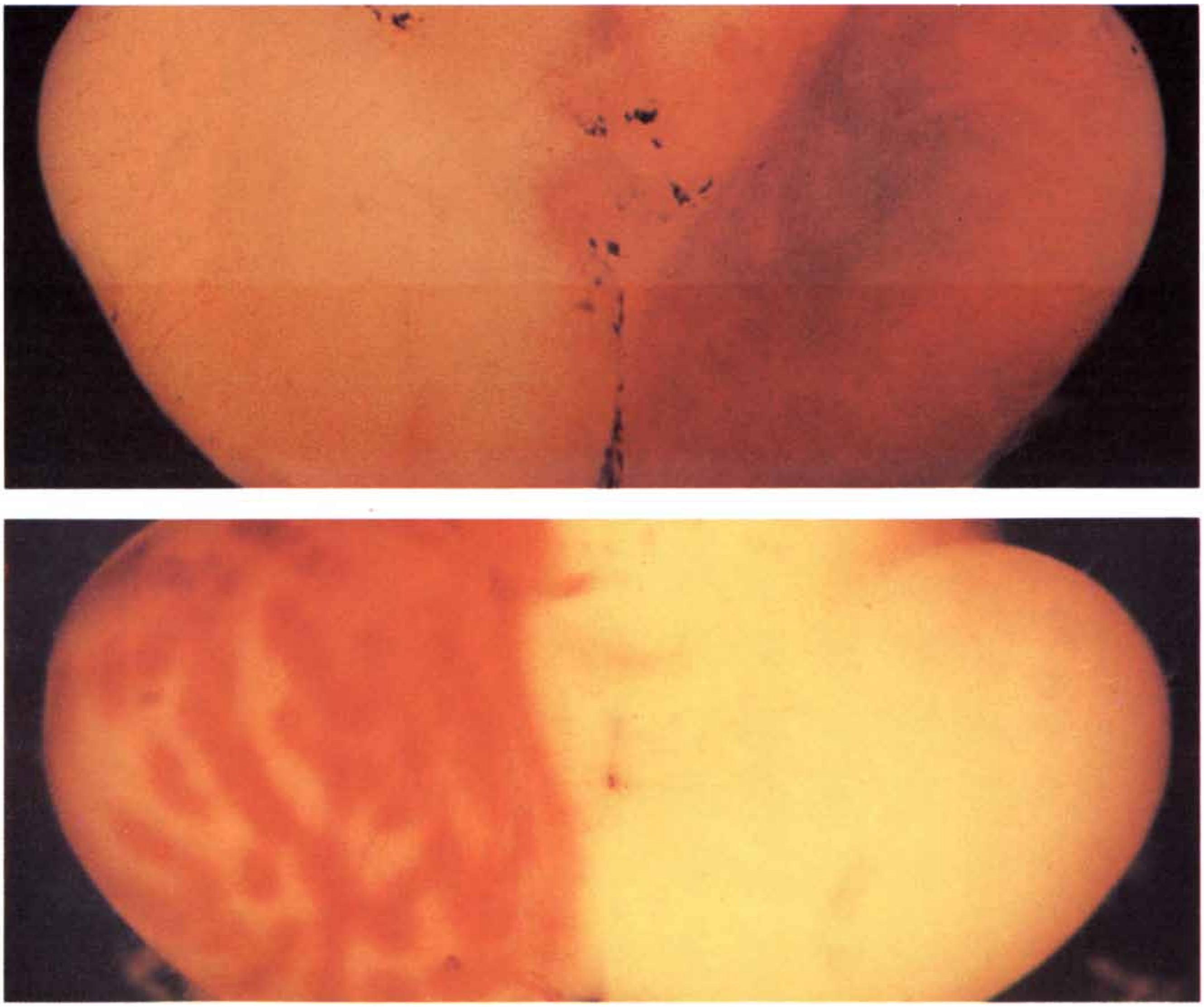
STRIPES IN A MAMMAL'S BRAIN are found in the visual cortex, the part of the cerebral cortex that gets data from the eyes. The tissue shown is about a fourth of the visual cortex on one side of the brain of a macaque monkey. One of the animal's eyes has been injected with a small quantity of an amino acid (proline) labeled with tritium, the radioactive isotope of hydrogen, and over a period of two weeks the radioactivity has been carried in axons, or nerve fibers, from the eye to the lateral geniculate nucleus of the brain and from there to the visual cortex. When slices of tissue from the visual cortex are coated with a photographic emulsion, the radioactivity exposes the emulsion in bright stripes. The stripes interdigitate with darker stripes representing the uninjected eye. Each stripe is about 350 micrometers wide. The image was provided by Simon LeVay of the Harvard Medical School; it is a montage produced from successive slices of tissue.

however, that when a microelectrode is passed through brain tissue in Layer 4 of the visual cortex, it records the electrical activity of neurons in a highly regular alternating sequence. An initial series of neurons might respond only to flashes of light in the animal's left eye. Then would come a series of cells responding only to the right eye, and then again a series of cells responding to the left.

Hubel, Wiesel and their colleagues have shown further that this functional alternation results from the segregation of the axons that carry information from each eye. The labeling of each eye's visual pathway with radioactive amino acids reveals stripes that run in a zebra-like pattern throughout Layer 4 of the visual cortex. Each stripe contains cells that respond exclusively to one eye, the left or the right. The cells in turn project their axons to binocular neurons in the cortical layers above and below them. In other words, every part of the visual world on which the cat or the monkey can train both of its eyes is represented twice in Layer 4: once at some point in a stripe of cells representing the left eye and again in a neighboring stripe representing the right eye.

Our own experiments at Princeton University capitalized on several properties of a considerably different visual pathway, that of the leopard frog (*Rana pipiens*). The experiments relied on a classical procedure of transplanting tissue in amphibian embryos. This transplantation, however, is combined with modern techniques of neuroanatomy and neurophysiology for examining the patterns of connections that neurons in the visual system make when they are placed in abnormal situations early in development. On occasion such analyses can reveal principles of growth and organization that are not obvious during normal development.

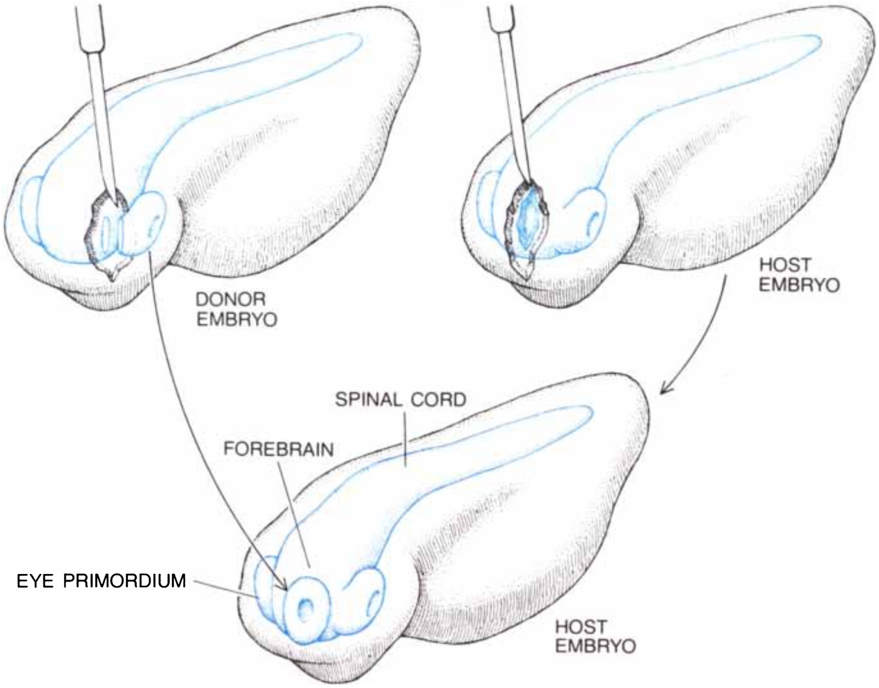
In one series of experiments we re-



ABNORMAL STRIPES in the brain of the leopard frog (*Rana pipiens*) strikingly resemble the stripes in the brain of a mammal. Here the stripes are revealed by injecting the enzyme horseradish peroxidase into one of the animal's optic nerves so that the enzyme is transported into the brain by the axons making up the nerve. The brain is then treated so that the enzyme produces a brown reaction product inside the terminals of the axons. The photograph at the top shows part of the brain of a normal frog. The view is from above. Each large lobe is an optic tectum, the brain region whose cells receive the optic nerve from the eye on the opposite side of the head. The optic nerve from the left eye has been injected with the enzyme; thus the tectum on the right is marked with reaction product. The even tone of brown suggests that the axons projecting to the tectum distribute their terminals there continuously. In this way the tectal cells embody a topographic map of the retina and therefore a map of the visual world. The photograph at the bottom shows the brain of an abnormal frog, one that developed with three eyes because the authors grafted a supernumerary eye primordium (a prospective eye) into the embryo. In this frog axons from the supernumerary eye compete with axons from a normal eye in establishing terminals in the tectum on the left. The supernumerary axons have been injected with the enzyme; they can be seen in the tectum, where their terminals are in stripelike regions. The stripes alternate with stripes of the terminals of axons from the normal eye. Each stripe is about 200 micrometers wide.

moved an eye primordium (the tissue that becomes an eye) from young embryos at a time when the eye was merely an outpouching of the embryonic central nervous system. We then transplanted the primordium into a second embryo in the region of its own two primordia. The embryos we treated in this way became tadpoles and then young frogs with three quite normal eyes. The supernumerary eye usually ended up in front of one of the normal eyes. Sometimes it was at the end of the nose or on top of the head.

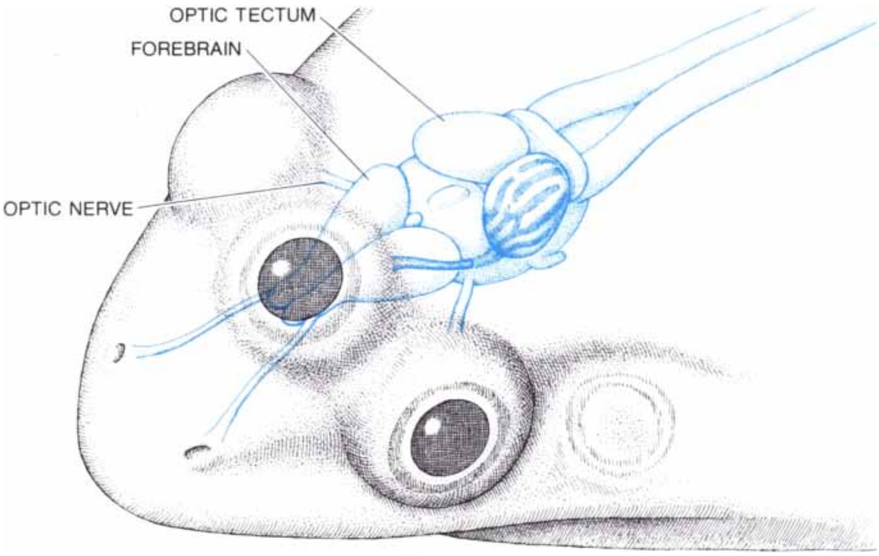
Leopard frogs rely heavily on vision, but unlike cats or monkeys their brains have not evolved the elaborate visual cortex that is characteristic of mammals. Instead the major area for the processing of visual information is in the optic tecta, a symmetrical pair of lobes that occupies much of the midbrain. Each optic tectum receives almost all its retinal axons from only one eye, the contralateral one (the eye on the opposite side of the animal's head). The projection from this eye creates a highly ordered map of the retinal surface, but since the tectum gets no massive projection from the second retina, there are no stripes representing each eye.



SURGICAL PROCEDURE that produces a three-eyed frog requires that an eye primordium be taken from one frog embryo and introduced into a second embryo after tissue has been removed to make room for it. At the time of the transplantation each embryo is some three millimeters long and each eye primordium is an outpouching from the developing forebrain.

The three-eyed frogs are different. In most of them the retina of the supernumerary eye sends axons predominantly to one optic tectum or the other. There the supernumerary axons compete with the normal input to the tectum: the axons arriving from one of the frog's normal eyes. We examined the brain of the three-eyed frogs by injecting radioactively labeled amino acids into either the normal eye or the supernumerary one and waiting a day or two for the isotope to be transported down the axons to their synaptic terminals in the tectum. The tectal lobes of these animals were then sliced and the slices were treated to reveal the distribution of labeled synaptic terminals.

The two sets of terminals (labeled and unlabeled) never mixed in a slice. Instead they were segregated into eye-specific zones that interdigitated periodically. Moreover, a tracing of the zones of labeled terminals through successive slices showed that the zones were aligned into stripes. Each stripe was about 200 micrometers wide and ran roughly from the front to the back of each lobe in a zebralike pattern. The pattern was always similar. It made no difference whether the supernumerary eye came originally from the right or the left side of a donor embryo or whether the axons from the supernumerary eye grew into the right or the left optic tectum. The trajectory taken by the supernumerary axons, the way they bundled together as they grew and the direction from which they entered the tectal lobe also made no difference.

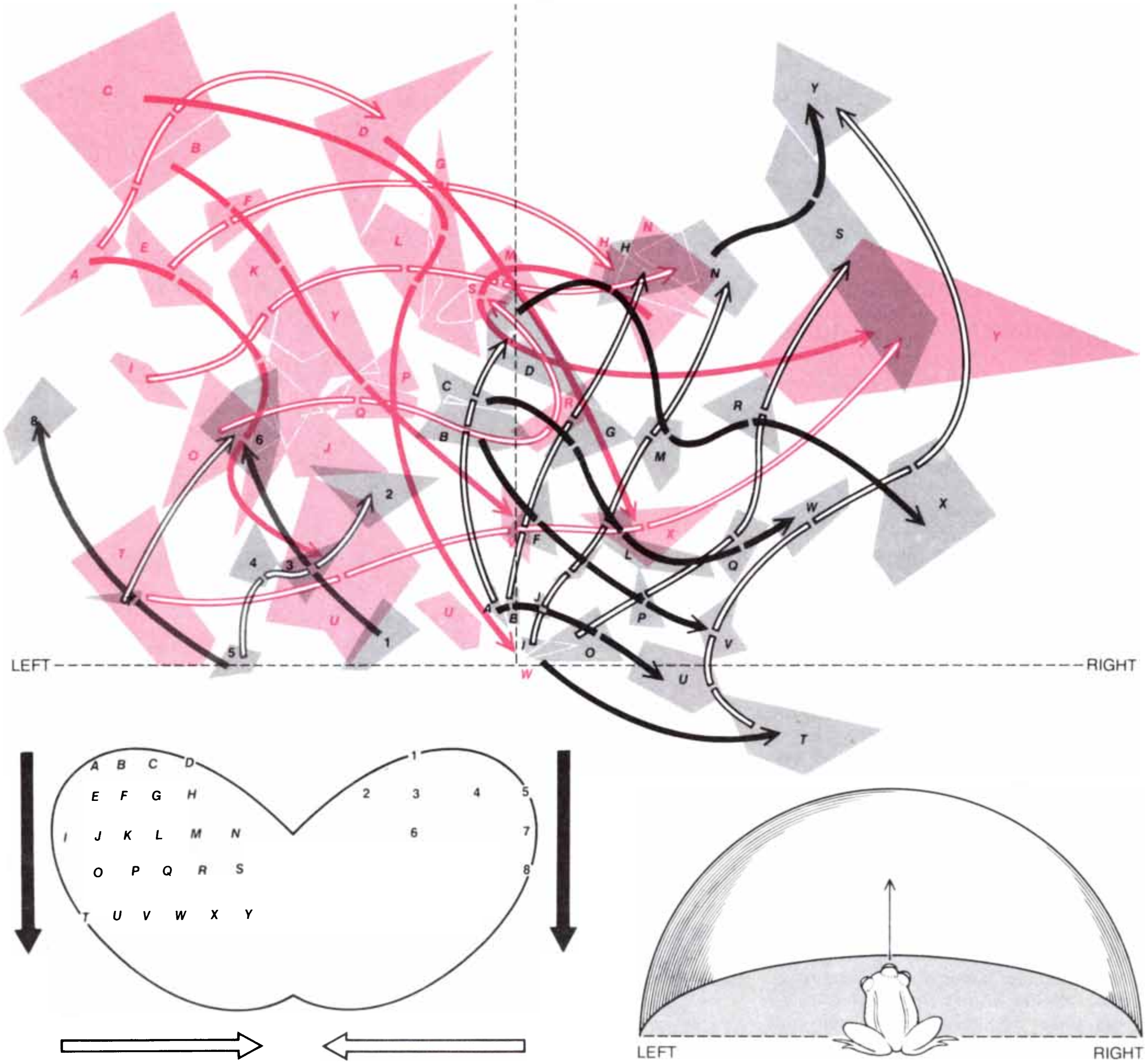


MATURE THREE-EYED FROG has two normal eyes positioned correctly on its head and a third eye either in front of a normal eye or on top of the head. In about three-fourths of all cases the third eye competes with a normal eye to establish axon terminals in one tectum.

In a related experiment several laboratories as well as our own removed one of the two tectal lobes from a normal frog or a goldfish. The axons from the retina that had projected to the missing lobe regenerated. They grew into the remaining tectum, where they competed with the projection already there and produced alternating stripes of terminals arising from axons of the left and the right eye. The experimental doubling of visual input to a tectal region that usually supports only one map of the retina seems inevitably to produce in a lower vertebrate animal a set of complex functional subdivisions that are strikingly similar to the pattern in the visual cortex of normal mammals.

In some of our three-eyed frogs we recorded the activity at the terminals of retinal axons in the tectum while we flashed spots of light on a screen in front of the frog. First we covered the normal eyes and then the supernumerary eye. In this way we could show that each eye's representation on the doubly innervated tectum was properly aligned with respect to the original axes of the eye in the embryo. Thus the axons in each projection maintained in the tectum a map of the retina from which they arose even though the map is interrupted by the interdigitating stripes. Here again the abnormal frogs resemble the normal mammal. Two retinal inputs produce two separate representations of the visual world in a single target structure.

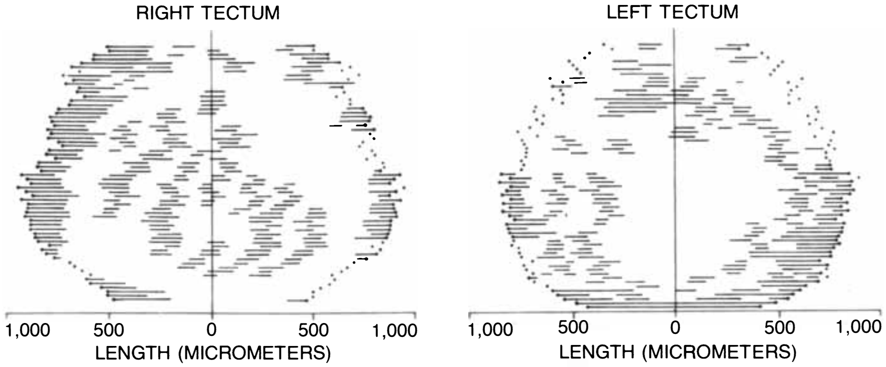
In a mammal, however, the two eyes are symmetrically positioned on the head. This is not the case in a three-eyed frog, where the supernumerary eye is positioned abnormally on the head. In a three-eyed frog the projection from the supernumerary retina to the tectum generally transmits a view of the animal's surroundings that is improperly matched to the view from the normal retina. This means that neurons near each other but in adjacent stripes in the tectum get information about unrelated parts of visual space. The situation could be simulated by fitting one of your own eyes with a prism that bent the light to that eye by, say, 90 degrees. As you looked around, the prism would transmit images from the sky above you into one eye while the other eye saw the terrain in front of you. Both images would be signaled simultaneously



ORIENTATION OF MAPS in the tectal lobes of a three-eyed frog is determined by recording the electrical activity of groups of retinal axons terminating at various places in each tectum as lights are flashed at various places on a hemispherical surface in front of the frog. The numbers *1* through *8* mark sites at which recordings were made in the tectum on the right side of the brain. They also mark receptive fields: the part of the visual world that the cells encountered at each site are found to monitor. In this case the tectum on the right side of the brain embodies a map of the world seen through the eye on the left side of the head (*gray*). Open arrows in the map link directions in the visual world monitored by axon terminals arrayed from side to side in the tectum; closed arrows link directions monitored by axon terminals arrayed from front to back. The letters *A* through *Y* mark sites of recording in the tectum on the left side of the brain. They also mark receptive fields. The tectum on the left side turns out to embody two maps, that of the normal right eye (*black*) and that of the supernumerary eye (*color*). At most recording sites the axon terminals representing each eye are close enough to be detected by a single recording electrode. Both maps are well organized in that when one of the two eyes is covered, the activity of cells in a succession of sites in the tectum can be elicited by stimuli in a succession of parts of the visual world. Yet the normal map and the supernumerary map are not in register: when the animal has both eyes open, neighboring groups of tectal cells may respond to quite different parts of the world.

to the same part of the visual cortex. The world would make little sense.

A three-eyed frog presented with an erratically moving object that mimics its prey (a flying insect) often remains immobile. Occasionally it strikes aberrantly at the stimulus. If the frog is allowed to see through its normal eyes but not the supernumerary one, the strikes are accurate. Presumably the tectal maps representing the normal eyes are correctly aligned with the motor pathways in the nervous system that control the frog's behavior. If the frog is allowed to see through only the supernumerary eye, the strikes are always misdirected. The motor pathways driven by the misaligned visual map move the animal's body in directions that are inappropriate to the prey's position in space.



MIRROR-SYMMETRICAL PATTERNS of stripes are found in a three-eyed frog in which the supernumerary eye sent axons to both optic tecta. Specifically, a hole in the pattern of stripes in one tectum corresponds to a mirror-symmetrical patch of stripes in the other. The patterns suggest that axons from the supernumerary eye compete in the tectum with axons from a normal eye only at particular parts of the tectum determined by where the axons arise in the retina. The surface of each tectum was reconstructed in the illustration by measuring the widths of the stripes in a series of sections of the tectum made at intervals of 20 micrometers.

Questions about the functional or evolutionary significance of stripes in the brain of three-eyed frogs are clearly irrelevant. The third eye is abnormal, and in the absence of substantial input from both of the normal eyes to a single optic tectum the normal frog would get no benefit from a mechanism that evolved specifically to segregate tectal inputs into stripes. On the other hand, the survival of free-living frogs, and in particular their ability to catch the insects on which they feed, depends critically on a robust mechanism to ensure that a precise map of the contralateral retinal surface develops in each tectum.

We began, therefore, to consider the possibility that stripes might arise from the same developmental mechanism that generates maps. Such a link was first suggested as early as 1975 by Simon LeVay, working in collaboration with Hubel and Wiesel at the Harvard Medical School. LeVay proposed that the functional stripes in the visual cortex of the monkey might represent a compromise between two conflicting tendencies: a spreading process in which the axons carrying information from each of the retinas try to fill the entire visual cortex with a map, and a grouping process in which the axons carrying information from each of the retinas try to remain together, as if they were repelled by the inputs from the other eye. The most likely result of the two conflicting tendencies would be interdigitated stripes because a striped configuration would simultaneously optimize both processes.

What, then, are the mechanisms that give rise to neural maps? How could these mechanisms give rise to stripes when two populations of axons map themselves in a single target zone? Fortunately the projections from the retina to the optic tectum of lower vertebrate animals have long been the subject of studies of neural mapping. R. W. Sperry of the California Institute of Technology was one of the first investigators. Sperry surgically rotated the eyes of newts 180 degrees. In some of the animals he left the optic nerves intact; in others he severed the optic nerves and allowed them to regenerate. In either case the newts made errors of 180 degrees when they snapped at stimuli, and the errors did not improve as time passed. The animals behaved as if they were unaware that their retinas had been rotated. Evidently each part of the retina continued to project its axons to a particular part of the tectum, in spite of the fact that Sperry had intervened so that each part of the retina now monitored abnormal parts of the visual world. Numerous later studies expanded on Sperry's work to show that the part of the tectum that will be innervated by a particular part of the retina is determined in the embryo even before the axons leave the retina and grow into the developing brain.

In 1963 Sperry proposed a theory to explain the consistent alignment of visual maps in the brain. He suggested that retinal cells and tectal cells develop in ways that depend on their position along each of two axes in the retina and the tectum respectively, so that each cell comes to have on its surface a unique set of marker molecules. Axons from the retinal cells can then synapse only with the tectal cells that bear the complementary markers. In short, Sperry visualized a rather rigid chemical-affinity matching between the retina and the tectum. The matching, however, cannot be absolute. Experiments on fishes and amphibians in several laboratories have shown that under some conditions retinal axons synapse with tectal neurons that are not their normal targets. A retina reduced to half its size by surgery can send its axons to form an expanded projection across an entire tectal lobe. Conversely, the axons from an entire retina can compress their map so that it will occupy a surgically created half tectum.

Clearly a mechanism based on a rigid matching of fixed markers on retinal and tectal cells cannot account for the plasticity indicated when the sizes of the retinal and tectal cell populations are surgically altered. Instead the positions of retinal axons in the tectum must be controlled by some mechanism that can adjust to changes in the relative numbers of retinal and tectal cells.

How is the adjustment accomplished? Three possibilities have been formulated. First, the rigid chemoaffinity markers proposed by Sperry could be capable of "respecification," so that surgical perturbation could cause the marker in the retina or the tectum to change. Second, instead of depending on many different markers the identification of cells in the retina or the tectum could depend on gradients of two marker substances, one along each of two axes.

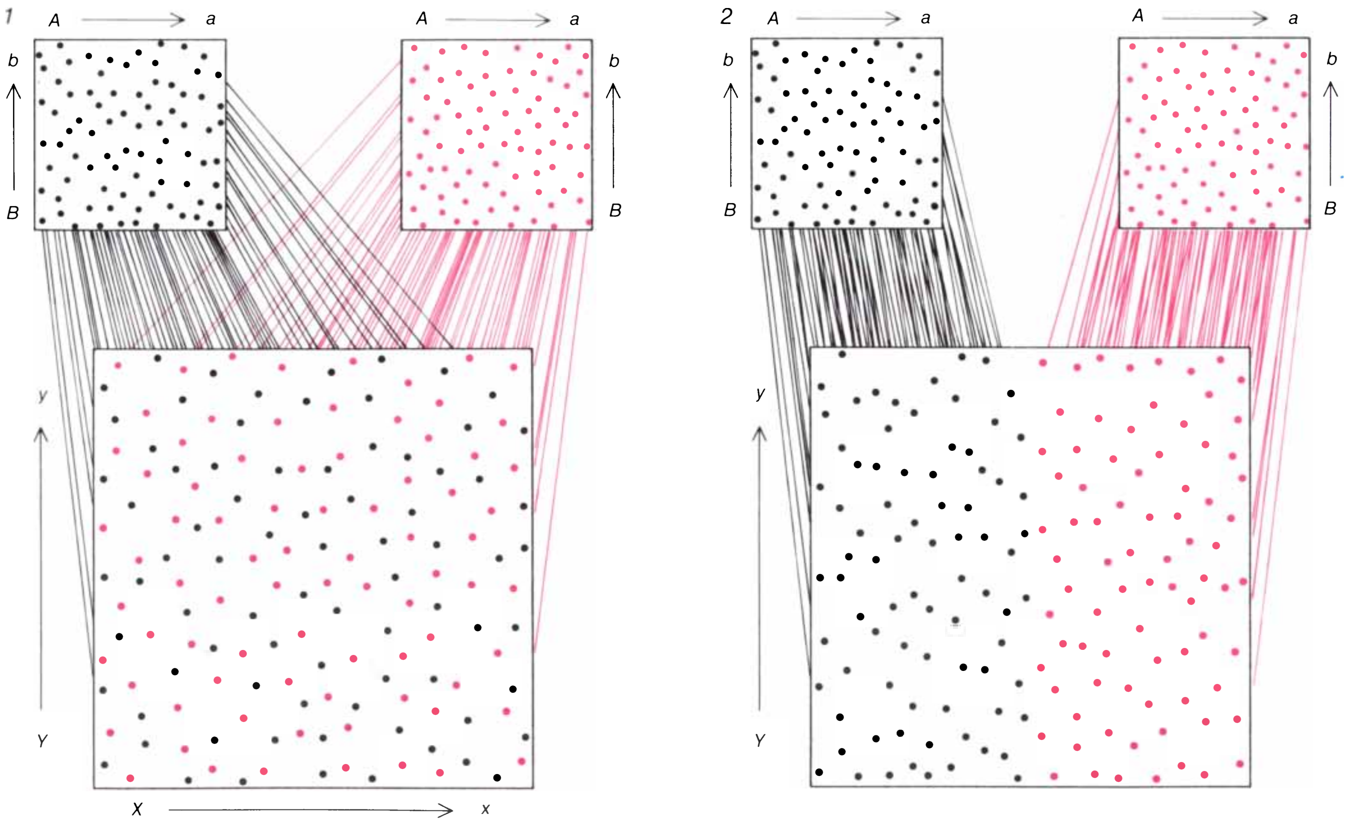
The third possibility is that the retina and the tectum have no markers at all. Instead the axons projecting from the retina to the tectum might maintain their relative order by a cohesion they maintain among themselves as they grow toward the tectum. One must then explain how the map as a whole comes always to have the same orientation in the tectum. In particular the retinal maps in all nonmammalian vertebrate animals represent the central part of the animal's visual world in the anterior (forward) part of the tectal lobe and the more lateral parts of the visual world in the posterior parts of the lobe.

Several lines of evidence are now available to help in evaluating these various possibilities. Indeed, the first possibility, the idea of changing or respecifying rigid retinal or tectal markers, may not be apt. For one thing a series of surgical manipulations done on goldfish in a number of laboratories has shown that a tectum can sequentially receive input from a normal retina, then from an expanded half retina, then from a normal retina again. In addition there are a few reports of experiments on frogs of the genus *Xenopus* in which a region of tectum (although possibly not the same tectal cells) simultaneously receives input from the embryonically anterior half of one retina and the embryonically posterior half of the other retina. Thus if tectal labels respecify, they are capable of doing so frequently. Moreover, the cells within a small region of the tectum can change their labels independently of their neighbors. The tectal markers must be so plastic that they could not identify a cell by its tectal position.

For their part, the markers in the retina, if they exist at all, do not seem to change. Scott E. Fraser, working at Johns Hopkins University, removed an eye from tadpoles of the frog *Xenopus*. The intact eye then projected axons to the contralateral tectum just as it would have done normally. In addition the ventral (lower) part of the intact eye, whose contribution to the optic nerve was still developing at the time of the surgery, sent axons to the full extent of the ipsilateral tectum, the one that would have been innervated by the eye that had been removed. If a ventral region of a retina can project an expanded map to one tectum and a normal map to the other, it must connect to cells in different tectal positions. This makes it unlikely that the expansion of a map involves the respecification of retinal markers.

The second possibility, that of graded markers in the retina and the tectum, accounts for expansions or compressions of a map. It accounts for the ability of cells in a given region of the tectum to receive axons from different parts of a retina. It also accounts for the ease with which a part of a retina can send axons to quite different parts of two tectal lobes. A separate gradient of a marker molecule along each of two axes is sufficient to provide each retinal and tectal position with a unique combination of markers, and the match between retinal and tectal positions is able to adjust to the range of the markers present in the retina or the tectum.

The hypothesis of graded markers predicts, however, that the orientation of a retina's projection on the tectum is maintained after any perturbation. A few experiments show otherwise. Ronald L. Meyer, working at the California Institute of Technology, removed half of a goldfish's retina. The removal eliminated the input to half of one tectal lobe. At the same time Meyer forced half of the axons from the other eye to grow into the half-vacant tectum. One might predict that the rerouted axons would end in the half-vacant tectum much as they would end in the tectum to which they normally project. In this experiment the axons Meyer rerouted would have ended in the part of the half-vacant tectum that retained its retinal input. Instead the rerouted axons formed a misoriented (in fact inverted) projection in the vacant half of the lobe. Apparently the rerouted axons from the center of the intact eye got as close to their appropriate tectal position as possible. The other rerouted axons, however, could not preserve both the continuity and the orientation of their retinal map because that would have forced them to terminate in the occupied part of the tectum. Meyer's study indicates that preserving neighborhood relations must be an important tendency that can operate independently in forming a map. After all, in Meyer's experiment neighborhood relations were maintained in an inappropriate region of tec-



CONCEIVABLE MECHANISMS by which maps in the brain develop are compared. Two retinas are at the top of each part of the illustration. Their cells (*dots*) are assumed to be labeled by gradients in the concentration of two substances (*A, B*) on the surface of the cells. A tectum to which the retinas send their axons is at the bottom of each part of the illustration. In the simplest form of the mechanism called chemoaffinity matching (*1*) the cells in the tectum are assumed to be labeled by gradients (*X, Y*) whose complementarity to the retinal markers guides the ingrowing axons. The axons from both eyes mix as they establish terminals in the tectum, a result that is never found in three-eyed frogs. In a somewhat different possible mechanism (*2*) the axons from each retina maintain their spatial order as

tum and at the expense of the normal orientation of the map.

Results of this kind seem to support the third possibility, which favors a cohesion among the axons growing toward the tectum and proposes that there is no chemoaffinity matching between retinal axons and tectal cells. Proponents of the idea cite studies indicating that in fishes, frogs and chickens axons from many (but not all) parts of the retina grow toward the tectum together with axons from cells that are their neighbors in the retina. As we have noted, however, the idea does not explain why normal maps are consistently oriented. The absence of retinal and tectal markers is also difficult to reconcile with a large number of experiments in which retinal axons disrupt the continuity of their map to terminate appropriately in a piece of tectal tissue that is rotated or transplanted to an abnormal position in the tectum.

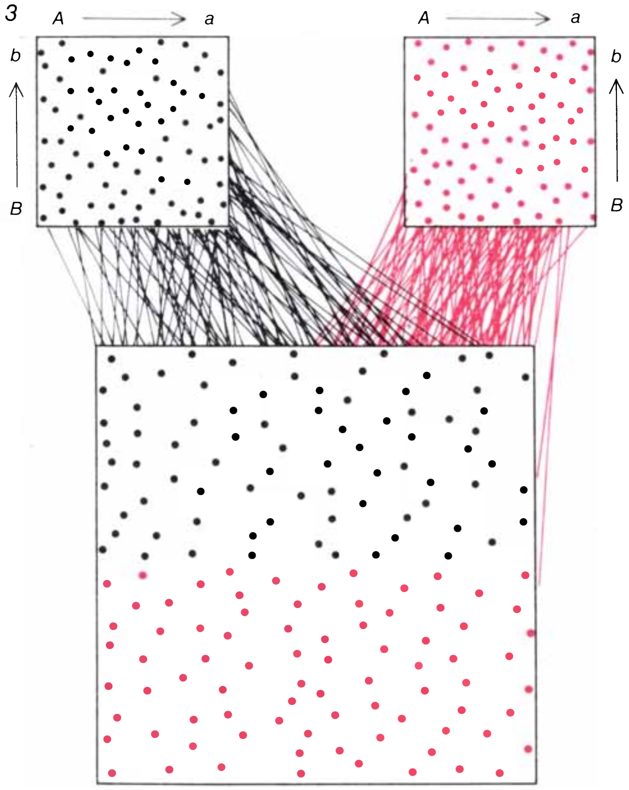
What most convinced us that retinal and tectal markers must exist was a finding we made in three-eyed frogs. In about a fourth of the frogs the supernumerary retina sent axons to both sides of the brain, so that neither tectum was completely striped. In such frogs a hole in the banding pattern in one tectum turned out to correspond to a patch of bands at the mirror-symmetrical location in the other tectum. If ingrowing axons from a third eye simply preserve the topology of the retina, the projections to the tecta should have expanded and formed stripes throughout both lobes. Apparently, however, the supernumerary axons can compete with the axons from the normal retina for tectal space only at locations that are appropriate for the part of the retina in which the axons arise. It seems, therefore, that tectal cells are marked and that retinal axons can discriminate between the tectal labels.

Moreover, recent work in our laboratory shows that a tectum never innervated by a retina can nonetheless develop a map. We removed both eye primordia from frog embryos well before they had begun to send axons into the brain. Later we traced the axonal projections by which the tecta had established maps in other parts of the brain. The maps were identical in eyeless and normal frogs. Thus tectal cells are able to express their positional identities independently of their connections with the retina. Clearly some form of information must be available in the tectum to ensure the proper registration of the retinal map with other visual maps in the brain.

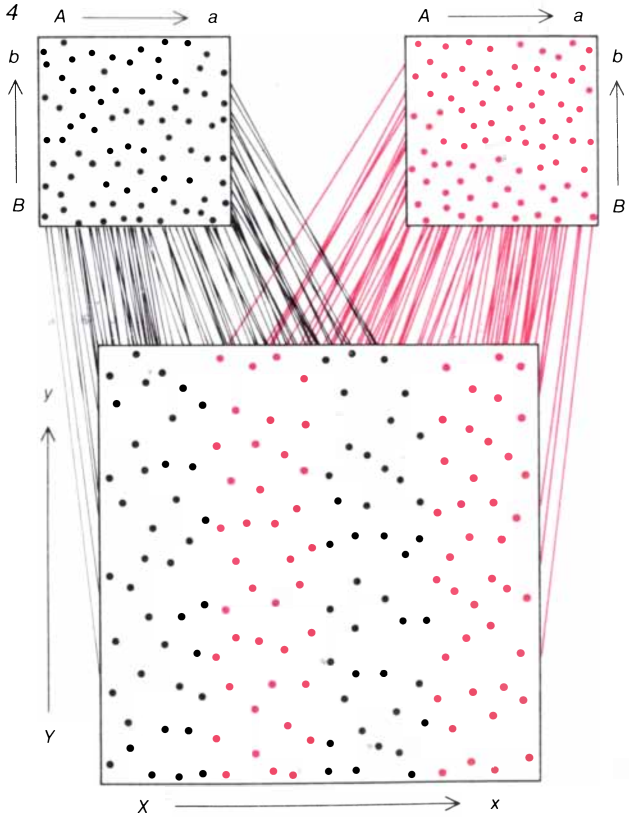
It now seems plain that no one simple mapping mechanism will resolve the controversies that emerge from the many experimental observations. On the one hand it appears that the axons from a certain part of the eye are able to seek out a certain part of the tectum. On the other hand a number of studies (and indeed the stripes in the doubly innervated optic tectum of three-eyed frogs) reflect a cohesiveness among the synaptic terminals representing one retina that cannot be explained by any chemoaffinity matching of retina to tectum.

If one assumes, however, that two independent mechanisms operate in the establishment of neural maps, many of the controversies disappear. Moreover, striping becomes a logical extension of mapping. Suppose that early in the development of a map chemoaffinities graded along at least two axes of the retina and the tectum guide ingrowing axons. The guidance need not be precise: the gradients could be shallow and the affinities could be quite weak. In the visual system of the leopard frog one need only assume that each axon arrives

3



4



they grow toward the tectum. The tectum itself provides only enough information (in this case a single gradient) to orient the map. Each retina innervates a separate district of the tectum, a result that is actually never found. In a further possible mechanism (*3*) the axons maintain their order but get no information from the tectum. In this instance they produce rotated maps. That too is never found. In still another possible mechanism (*4*) two processes operate. First an imprecise chemoaffinity matching spreads terminals over the tectum in proper orientation. Then a set of local interactions maintains as neighbors in the tectum only the terminals of axons arising from cells that are neighbors in one of the retinas. Stripes are the result because only stripes simultaneously optimize each of the two processes.

in the appropriate quadrant of the tectum. The precision of the map would result from a second stage of development, in which interactions in the tectum would maintain as neighbors only those axon terminals arising from cells that are neighbors in the retina. The result of this sequence will be the compromise recognized by LeVay, Hubel and Wiesel, in which the target zone of two projections is divided into elongated terminal bands.

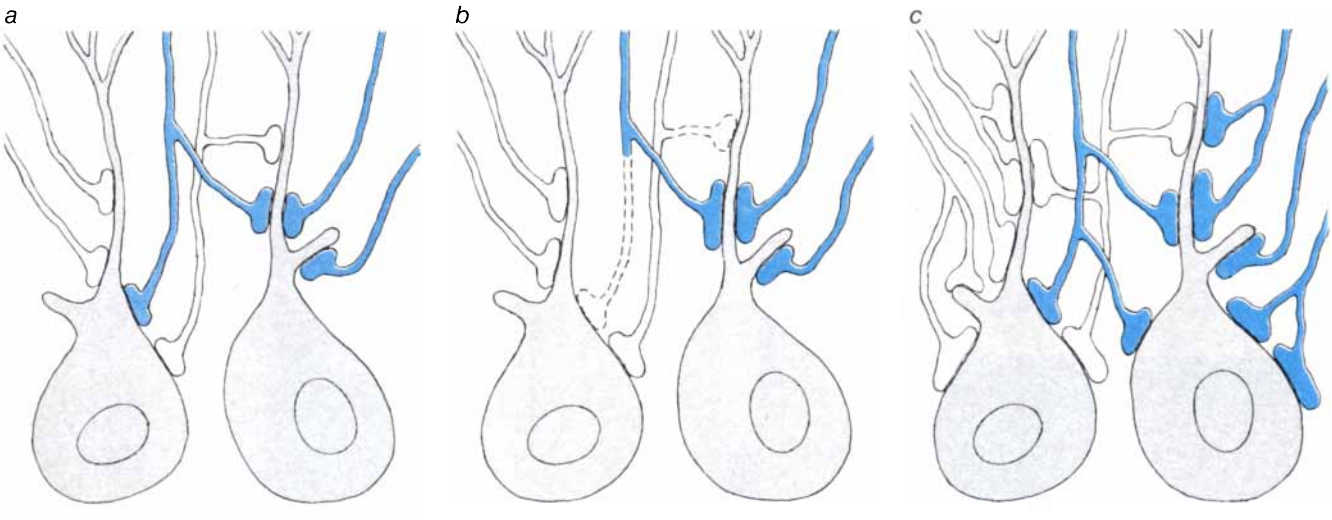
The appeal of chemoaffinity as a hypothesis has inspired investigators to search for marker molecules on the surface of cells in the retina and the tectum. The molecules must be distributed across the retina or the tectum with a gradient and with an ability to bind other substances that could give rise to the known alignment of the tectal map. Several recent advances promise success. For example, workers in the laboratory of Marshall W. Nirenberg at the National Heart, Lung, and Blood Institute expose cells of the immune system of the mouse to extracts of the retina of the chick. The cells in the mouse's spleen that make antibodies are then isolated and cloned. Each resulting cell culture manufactures a highly specific antibody, and one of the antibodies obtained in this way turns out to bind in a graded manner to cells along one axis of the retina. It follows that the unknown molecule to which the antibody is binding has a similar graded distribution. Taking a different experimental approach, Willi Halfter, Michael Claviez and Uli Schwartz of the Max Planck Institute for Viral Research in Tübingen have addressed the question of adhesion between the retina and the tectum. They find that axons from different parts of the chick retina show consistent differences in their ability to bind membranes isolated from chick tectal cells.

Basic questions continue, however, to surround the second stage of mapping: the interactions that keep the terminals from neighboring cells together and presumably give rise to stripes. Michael P. Stryker of the University of California School of Medicine in San Francisco has shown that tetrodotoxin, a drug that blocks the ability of neurons to signal one another by means of the voltage spikes called action potentials, prevents or delays the development of stripes in the visual cortex if it is injected into the eyes of a kitten. The projections of the eyes remain mixed in their cortical target zone. N. V. Swindale of the University of Cambridge has reported similar results after raising kittens in the dark.

Apparently neural activity is essential for the cohesiveness among the synaptic terminals that represent one eye or the other. How might this work? Within a given retina neighboring cells that project their axons to the tectum (or toward the visual cortex) tend to generate similar sequences of action potentials because they are connected (by way of intermediate retinal neurons) to many of the same light-receptor cells. Moreover, the correlated action potentials from neurons that are neighbors in the retina are more likely than uncorrelated signals to induce electrical activity in a given tectal cell. Hence well-correlated activity at pairs of synapses could conceivably serve in the tectum (or the visual cortex) to label the synapses from cells that are retinal neighbors. If the tectal neurons were to reinforce synapses from several well-correlated neurons at the expense of synapses whose signaling is relatively ineffective, a roughly topographic map would become precise.

In sum, a two-mechanism model of how the tectal map develops proposes the existence of weak graded affinities that roughly align the retinal axons in the tectum. The map is then precisely ordered by the strengthening of synapses from neighboring retinal cells, which tend to be active simultaneously. Cristoph von der Malsberg and David Willshaw of the Max Planck Institute for Biophysical Chemistry in Göttingen have devised computer simulations in which the selective reinforcement of synapses acts on two roughly topographic projections in a single target zone. They find that the simulations give rise to maps with stripes.

The idea that the efficacy of synaptic terminals can determine their stability and their position in the brain is neither recent nor limited to maps. In the 1940's D. O. Hebb of McGill University suggested that the selective strengthening of synapses might underlie certain aspects of learning. Variants of Hebb's suggestion have since been made to account for the development of neural circuitry in the cerebellum, for the sensitivity of sensory neurons to particular stimuli and for the maturation of the motor connections between the nervous system and the muscles. Although neuroscientists are still far from unraveling the molecular mechanisms that would underlie the selective strengthening or stabilization of synapses, the concept itself is helpful in the effort to understand how neural activity can influence neural structure. Action potentials and the relative effectiveness of synaptic signals are quite likely to be the link between maps and stripes in the brain. They may indeed fine-tune the developing nervous system.



CELLULAR EVENTS thought to underlie the development of a precise tectal map are diagrammed for two cells in a tectum innervated by two eyes. An initial episode of chemoaffinity matching leaves local overlaps in which axons from different eyes impinge on the same tectal cells (*a*). Then the terminals representing one eye are strengthened (in the drawing they are assumed to get bigger) at the expense of terminals representing the other eye (*b*). In addition the density of "correct" terminals could increase (*c*). In either case each retina comes to dominate groups of cells. The terminals representing cells that are neighbors in a retina are likely to transmit well-correlated signals. This correlation could underlie the strengthening of precisely mapped connections and at the same time be responsible for stripes.

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SCIENCE AND THE CITIZEN

Secrecy v. Security

Recent efforts by members of the Reagan Administration to impose a variety of new restrictions on the open communication of unclassified scientific information in the name of national security are for the most part unwarranted and likely to be counterproductive. That is the main conclusion to emerge from the work of a special panel appointed eight months ago by a joint committee of the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine. The 19-member panel, headed by Dale R. Corson, president emeritus of Cornell University, was charged with the question "What is the effect on national security of technology transfer to adversary nations by means of open scientific communications, either through scientific literature or by person-to-person communications?" Besides Corson the group included senior members of university faculties and administrations, former Federal officials and executives of high-technology companies. Support for the study was provided by the Department of Defense, the National Science Foundation, the American Association for the Advancement of Science, the American Chemical Society, the American Geophysical Union and a consortium of private foundations.

According to the panel's two-volume report, *Scientific Communication and National Security,* much of the current conflict between the Administration and the university-based research community over the censorship issue stems from a series of actions taken by several Federal agencies, starting early in 1980. For example, university scientists and engineers working under contract with the Department of Defense, particularly in microelectronics, have been cautioned that the routine dissemination of their research results without prior Government approval might henceforth violate existing contractual obligations or export regulations. On several occasions unclassified papers have been withdrawn on short notice from international scientific conferences at the insistence of Government officials, and permission for visits by foreign scientists has been abruptly denied. In addition universities have been asked to help in monitoring and enforcing restrictions on the movements of foreign scientists and foreign students on the campus.

In an apparently related move the U.S. Customs Service, under the code name Operation Exodus, has detained and searched foreign students returning home and has blocked the shipment to other countries of various items, ranging from the weekly computer tapes of *Science Citation Index* to the chess-playing computer named Belle. More recently the Administration has proposed amending the Freedom of Information Act to exempt certain categories of information from disclosure, and it has issued a new executive order on security classification that frees the Government from the obligation to show due cause when it makes a classification decision. (Consideration has reportedly also been given to removing the special exemption for basic research from the executive order on classification.)

High-ranking Administration officials have attempted to justify these measures and similar ones on the grounds that they are necessary to prevent the growing "leakage" of militarily significant scientific information to "adversary nations," particularly the U.S.S.R. The chief concern seems to be that the nation's traditional mechanisms for protecting military secrets (mainly classification and specific conditions written into research contracts) may have become inadequate, given recent trends in military technology.

It was expressly to deal with such concerns that the independent panel on scientific communication and national security was set up. In reviewing the available evidence on the "leakage" problem some members of the panel were given top-secret briefings by members of the intelligence community. In general they found support for the view that "there has been a substantial transfer of U.S. technology—much of it directly relevant to military systems—to the Soviet Union from diverse sources." Nevertheless, the full panel emphasizes in its report, "there is a strong consensus... that universities and open scientific communication have been the source of very little of this technology transfer problem. Although there is a net flow of scientific information from the United States to the Soviet Union, consistent with the generally more advanced status of U.S. science, there is serious doubt as to whether the Soviets can reap significant direct military benefits from this flow in the near term. Moreover, U.S. openness gives this nation access to Soviet science in many key areas, and scientific contacts yield useful insights into Soviet institutions and society."

In assessing the likely costs and benefits of tighter controls on scientific communications the panel points out that such controls "can be considered in the light of several national objectives. Controls can be seen to strengthen national security by preventing the use of American results to advance Soviet military strength. But they can also be seen to *weaken* both military and economic capacities by restricting the mutually beneficial interaction of scientific investigators, inhibiting the flow of research results into military and civilian technology, and lessening the capacity of universities to train advanced researchers. Finally, the imposition of such controls may well erode important educational and cultural values." Elaborating on the last point, the report cites the panel's unanimous belief that "the costs of even a small advance toward Government censorship in American society are high. The First Amendment's guarantees of free speech and a free press help account for the resiliency of the nation. If political authority is to be exercised effectively, there must be trust in Government on the part of those affected—a trust that is promoted by openness and eroded by secrecy. Openness also makes possible the flow of information that is indispensable to the well-informed electorate essential for a healthy democracy."

On the basis of its assessment of the costs and benefits of tighter controls the panel concludes "that the best way to ensure long-term national security lies in a strategy of security by accomplishment, and that an essential ingredient of technological accomplishment is open and free scientific communication. Such a policy involves risk because new scientific findings will inevitably be conveyed to U.S. adversaries. The Panel believes the risk is acceptable, however, because American industrial and military institutions have the capacity to develop new technology with a speed that will continue to give the U.S. a differential advantage over its military adversaries."

"In any event," the report continues, "more than national security is at issue. Basic research investigations undertaken today may lead to applications in the long term.... To attempt to restrict access to basic research would require casting a net of controls over wide areas of science that could be extremely damaging to overall scientific and economic advance as well as to military progress. The limited and uncertain benefits of such controls are, except in isolated areas, outweighed by the importance of scientific progress, which open communication accelerates, to the overall welfare of the nation."

Accordingly the panel recommends that "the vast majority of university research, whether basic or applied, should be subject to no limitations on access or communications." In the rare cases where it can be demonstrated that Government-supported research will lead to military products in a short time, the report suggests, "classification should be considered" (although, it is noted,


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most universities will not undertake classified work, and some will undertake it only in off-campus facilities). Finally, there are in the panel's view a few "gray areas" at the ill-defined boundary between basic and applied resarch where some limited control measures short of classification may be appropriate. These measures, the report says, should be specified by contract before the work is undertaken and should in no instance involve the extension of existing export regulations.

EJ and v-ras

Some viruses that cause cancer in animals have a single gene that is responsible for oncogenesis, or the origin of a tumor. Such genes are called oncogenes. Some tumor cells that have nothing to do with viruses also harbor oncogenes. Both kinds of oncogenes are virtual copies of ordinarily benign genes in normal animal cells; they apparently share a common origin in those normal genes. Recently some of the oncogenes discovered in viruses have been shown to be essentially identical with some of the oncogenes in tumors that are not virally induced. There seems, in other words, to be a single class of cancer genes: genes that are resident in normal cells but that on occasion can be triggered, by a wide variety of carcinogenic agents, to promote cancerous growth.

The viruses that have oncogenes are retroviruses: their genetic material is not DNA but RNA, which is transcribed "backward" into DNA when the virus infects a cell. The best-known retroviral oncogene is a gene called *src* (for sarcoma) in the Rous sarcoma virus, which infects chickens. The gene was identified in the early 1970's and the protein it encodes was isolated and characterized. Then in 1976 *src* turned out not really to be a viral gene at all. It is a viral version of a normal chicken gene: a "proto-oncogene" that was somehow picked up by the virus and in the process became an oncogene. The viral gene (v-*src*) and the related cellular proto-oncogene (c-*src*) encode proteins that are indistinguishable by the usual immunological techniques. Some 15 proto-oncogenes have now been identified in vertebrate animals by virtue of their having been discovered as oncogenes in one or another retrovirus. One of them is c-*ras,* a murine (rat and mouse) gene whose viral analogue (v-*ras*) can give rise to leukemia or sarcoma.

The nonviral oncogenes were discovered more recently by a different route: gene transfer, or "transfection." Robert A. Weinberg of the Massachusetts Institute of Technology, Geoffrey M. Cooper of the Harvard Medical School, Michael Wigler of the Cold Spring Harbor Laboratory and their colleagues introduced gene-size bits of DNA from various tumors into mouse cells. The transfected cells were transformed, that is, they were converted to uncontrolled cancerous growth. In other words, the bits of acquired DNA were oncogenes. The tumor oncogenes, like the viral ones, turned out to be closely related to proto-oncogenes in normal cells. A number of different tumor oncogenes (and their proto-oncogenes) have now been identified. One of them was isolated by several groups of workers from a human bladder-carcinoma cell line called *EJ.*

Two very different lines of investigation, then, have each defined a distinct group of oncogenes. Earlier this year it turned out that the two groups are related, or at least overlap. Workers in several laboratories found that the *EJ* bladder-cancer oncogene is a homologue of the *ras* gene found in the Harvey strain of the murine sarcoma virus, that is, the sequence of the nucleotides (the subunits of DNA) is so similar in the two genes that single strands of the DNA's will hybridize, or pair up to form a double strand. Several other instances of homology between viral and nonviral-tumor oncogenes have been reported. Weinberg has suggested that the 20 or so currently recognized oncogenes may eventually turn out to be members of only a few families.

What is it about an oncogene that makes it oncogenic? There are two obvious possibilities. One is that it is a matter of control: an oncogene simply makes too much of some normal protein because it is regulated—turned on and off—differently from the way its normal progenitor is regulated. This "dosage hypothesis" has seemed to be borne out in the case of viral oncogenes. The other possibility is that the protein encoded by an oncogene is abnormal as the result of mutations that alter the gene's nucleotide sequence. This "mutation hypothesis" has now been strongly supported in the case of the *EJ* bladder-cancer oncogene as the result of work done by a group in Weinberg's laboratory in cooperation with groups headed by Edward M. Scolnick, Douglas R. Lowy and Ravi Dahr of the National Cancer Institute. Their results are reported in *Nature.*

Scolnick and Lowy had cloned the normal human *ras* gene—the *EJ* gene's proto-oncogene. Weinberg's group had cloned the *EJ* oncogene. Clifford J. Tabin, Scott Bradley, Cornelia Bargmann and Weinberg found—as might have been expected—that mouse cells transfected with the *EJ* oncogene were transformed, whereas cells transfected with the normal gene were not transformed. Yet the transformed cells and the untransformed ones contained comparable amounts of the protein encoded by the oncogene (or the proto-oncogene). That finding argued against the dosage hypothesis; it implied that the two genes were somehow different, presumably as the result of mutation. Tabin and his colleagues looked for the site of the difference. In a recombinant-DNA version of a classic "crossing-over" experiment, they cut out a small stretch of the *EJ* oncogene and interchanged it with an analogous piece of the proto-oncogene. They did the same thing with a large number of different small stretches of these 6,000-nucleotide genes. They tested each pieced-together gene to see if the oncogene had lost the capacity to transform transfected cells and the proto-oncogene had gained it.

Eventually Tabin and his colleagues identified a very short (350-nucleotide) segment of the DNA whose crossing-over transferred the power to transform. They determined the nucleotide sequence of this segment in the *EJ* oncogene and in the normal gene. Triplets of the four nucleotides *A, G, T* and *C* form the codons specifying the order in which amino acids are assembled into a protein chain. The sequences of the two 350-nucleotide segments are identical except for one nucleotide: a codon that reads *GGC* in the proto-oncogene reads *GTC* in the oncogene. The oncogene codon calls for the amino acid valine rather than glycine, which is specified by the normal gene. The nearly identical proteins encoded by the two genes are enzymes. The implication is that the substitution of valine for glycine at a particular site is sufficient to make a normal enzyme, which presumably has a role in the normal function of a mammalian cell, into a cancer enzyme.

The hypothesis that oncogenesis results from the alteration of a protein appears to be supported by this result, but the situation is complicated by an earlier report in *Nature.* Scolnick and Lowy, working with Esther H. Chang and Mark E. Furth, found evidence that the *EJ* proto-oncogene can also be activated to become an oncogene by a regulatory change. They connected the normal cellular gene to a control element taken from either a murine or a feline retrovirus. Cells transfected with this "up-regulated" normal gene were transformed. They also contained high levels of the *ras* protein. Taken together, the results of the two experiments may mean that the same normal-cell gene can promote cancerous growth either because it is altered to specify a slightly different protein or because it is differently regulated and makes more of the same protein.

Hérédité v. Environnement

In a now famous article published in the *Harvard Educational Review* in 1969 Arthur R. Jensen of the University of California at Berkeley questioned how much scores on I.Q. tests could be raised by changing the environment in which the student is raised and educat-

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ACCOUNTING

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Accounts Receivable Balance Forward
Accounts Receivable/Sales Analysis
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AMI Client Write-Up
Asset Record System
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Billings Management
Bookkeeper II General Ledger
Bookkeeper II-Depreciation
BPI General Ledger
Business Accounting
Business Check Register and Budget
Business Control System
C.P.A.
Client Accounting System
Construction Accounting
CPA Client Write-Up
Datawrite Client Write-Up System
Delivery Service Automation
Depreciation Calculations and Reports
Executive Accounting System
Financial and Management Accounting
Financial Partner
Fixed Asset Accounting
Fixed Asset Depreciation
Fixed Assets/Depreciation Schedules
Fund Accounting System
General Accounting
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General Ledger
Glector
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IRAP
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MAXILEDGER
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MICROLEDGER
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Nominal Ledger
One-Type Accounting System I
One-Type Payroll and Accounting
Paysystem Accountant
Peachtree General Ledger
SBCS General Ledger
SNIP — Integrated Accounting
TCS Accounting
TCS Client Ledger
TCS General Ledger
TCS Total Ledger
The Accountant Finance Data Base
The Bookkeeper System
The Boss Financial Accounting
The Business Bookkeeping System
The Controller
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The Software Fitness Program

AGRICULTURE

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Corn Harvest Losses
Corn vs. an Alternate Crop
Cow-Calf Profitability
Crop Yields
Economics of Corn Production
Farm Management
Farrow-To-Finish Swine Production
Feeder Pig Production
Fertilizer Formulation
Field Population
Field Size
Finishing Feeder Pigs
Job Cost (Crop Cost)
Least Cost Fertilizer Application
Liming Soil
Liquid Manure and Fertilizer
Net Energy for Feedlot Cattle
PEDIGREE-5 Generation Annotated
Pedigree
Protein Balancing for Feedlot Cattle
SBCS Agri-Ledger
Selling Wet Corn vs. Dry
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Soil Erosion
Soybean Harvest Losses
Swine Ration Analysis
Swine Ration Formulation

APPLICATION PROGRAM DEVELOPMENT AIDS

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APEX-6502 Assembly Language
Apple-80 Disassembler
Assembly Language Development
System
AUDEX-Audio Programming Aid
CBASIC Program Maintenance Utilities
CINDEX
Cosapple 1802 Disassembler
CRTFORM Programmer Productivity
Diagnostics II
DISTEL-Disk Based Disassembler
Executive Planning System
Floating Point Dictionary
Forms 2
Key Perfect-Checksum Table Generator
Linkdisk-Disk Utility for Apple Pascal
Linkvideo-Screen Utility
Lower Case Character Generator
MULISP/MUSTAR-80
OGI-Forth-Implementation of FIG-Forth
Pascal Programmer
Pascal Level 1
Pearl III-Rapid Logic Generator
Personal Programmer
Prism/Ads Data Base Generator
Program Development System I
Program Writer for Non-Programmers
Programming Aids 3.3
Quic-N-Easy Application Development
RAID-Real Time Assembly Debugger
Scientific Data Base
SID-Symbolic Instruction Debugger
Stok Pilot-Menu Generator
STRING-80
STRING-BIT
Systems Analyst
Teacher Plus Teaching & Reference Pkg
The BASIC Teacher
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The Toolbox Programming Utilities
Tiny-C-Interactive Programming
UCSD Pascal
Unlock Development Tool
V-COM Disassembler Package
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Financial Planning Series
Financial Planning/Analysis
Finplan/Financial Planning
FP2020 Financial Planner
FPL-Financial Planning Language
Magic Worksheet
Magicalc-Forecasting Package
Micro-DSS/Finance
Microfinesse-Financial Modeling
Milestone-Critical Path Network Analysis
Optimiser
PFS-Personal Filing System
Personal Report System
Plan 80-Financial Planning & Analysis
Project Boss-Mgr's Cost Control System
Project Planning and Budgeting
Retail Purchasing & Pricing
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The Analyzer
The Budget Planner
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Smarterm-CP/M Terminal Program
Term II-Computer Intercommunications
Term Intercommunications Package
TTY-Communications With Other
Computers
U-Net-Shared Resources Network
Ultimate Transfer
Visiterm-Communications Program
VT-100 Emulator
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DATA MANAGEMENT

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CBS-Configurable Business System
CCA Data Mgt System
CM 2020 Configurable Manager
Condor Series 20
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Data Manager
Data Master
Data-View Electronic Filing Cabinet
Database II
Database Management
Datafax
Dataflow-Info Processing
Datastar
Datastore
Datatree
Disk-Edit-Screen Oriented Disk Editor
DMS-Data Mgmt System
FABS II-Rapid Keyed Access
Fast Entry for Tabs Business Modules
FINDAFYL-Reference Retrieval System
FMS 80-Data Base Management System
GBS Database
General Database
HDBS-Hierarchial Data Base
IFO Database Manager
Information File Organizer
Information Master-Data Mgmt System
KTDS-Key to Disk, Data Entry
Linkindex-Pascal Utility
MAG/Base-Data Base Management
Manager-Relational Data Base
MDBS.DRS-Micro Database Mgt System
MUMPS-Language for CP/M Database
Optimum Data Mgmt Program
PRISM/IMS-Information Mgt System
RADAR-Random Access Data Acquisition
Reprogrammable Data Base
Scientist-Data Base & Statistical Pkg
Selector III-Data Base Processor
Selector IV-Data Base Mgt
Selector IV-Key Access Info
Selector V-Data Base Mgmt
STATPRO-Integrated Database System
Stoneware Utility Package
Super Kram II — Multi-Keyed
Random Access
The Reprogrammable Data Base Program
VisiDex-Data Base Mgt System
VisiFile-Data Base Mgt Package
Whatsit?-Conversational Query/Retrieval

DATA SECURITY SYSTEMS

Absolute Security
Encode/Decode Security System

DISTRIBUTION

ABT Retail Manager
Beer Distributor Management
Inventory, Order Entry, Invoicing
Oil Jobber Management System
Order Entry and Inventory Control
The Store Manager
Wholesale/Retail Distribution System

EDUCATION — BUSINESS

Accounting Tutor
Comparative Buying
Income Meets Expenses
Interactive Typing Tutor
Job Readiness-Assessment &
Development
Mastertype-Typing Instruction
Money Mgmt Assessment
Typing
Typing Tutor
You Can Bank On It-Bank Concepts

EDUCATION — CHEM/PHYSICS

Acid-Based Chemistry
Atomic Structure
Chem Lab Simulation
Chemical Equilibrium
Chemistry With A Computer
Fundamental Skills for General Chemistry
High School Chemistry
High School/Jr. College C.A.I. Biology
High School/Jr. College C.A.I. Physics
Organic Nomenclature
Physics

EDUCATION — ENGLISH

A Batch of Endings
Agreement of Pronoun/Antecedent
Alphabetize
Capitalization
Catalog Cards
Commas
Compu-Read
Compu-Spell
Coordination
End Marks
Excess Words
Faulty Coordination
Hearing the Homonyms
Irregular Verbs
Is It "ie or ei?"
Language Drill
Locate Books on the Shelf
Magic Spells
Misplaced Modifiers
Parallel Structure
Possessing the Possessives
Prefixes & Suffixes
Quotations
Reading Level
Readings In Literature
Run On Sentences
Scramble
Sentence Diagramming
Sentence Fragments
Speedreader
Spell-N-Time
Spelling Bee with Reading Primer
Spelling Those Plurals
Still More Nasty Demons
Subject/Verb Agreement
Subordination
The End of the Endings
Those Nasty Demons
Understand the Card Catalog
Understand the Title Page
Use an Index
Use the Table of Contents
Using Adjectives/Adverbs Correctly
Word Scrambler & Super Speller

EDUCATION — MATH

Addition & Subtraction
Algebra I
Basic Math Skills
Compu Math: Arithmetic Skills
Compu-Math Decimals
Compu-Math Fractions
Counting Bee
Decimal Estimation
Division Drill
Drill II
Elementary Math
Fractions
Geometry
Geometry and Measurement Drill
Lessons in Algebra
Matching and Using Numbers
Matching Geometric Figures
Math-Addition & Subtraction
Matrix Mathematics Package
Measurements
Multiplication & Division
Mumath-PO Symbolic Math
New Subtraction
Numerical Analysis Mathematics
Problem Solving
Problem Solving in Everyday Math
Sets
Sign Drill/Typing
Statistical Analysis I Mathematics
Statistics 3.0
Typing Fractions

EDUCATION — MISC.

2ES Courseware
American History Through
Biographies
American Indians
Antonyms
Apple Sack 2 Home Education
Approximate Measure
Astronomy I & II
Concentration-Taxing
Counting Calories
Early Civilization
Educational Package
Educator's Disk
Family Fun
Farm and Farm Products
HI-Res Life
History
Home Safe Home
Insects
Light Pen Quiz
Literature
Living Things
Math, Sports, Etc
Middle Ages
Money
Moptown
Mother Goose Rhymes
Music/Art
Our Bodies
Poison Proof Your Home
Questions & Answers in Biology
Questions & Answers in History
Quizstat
Reverse/Sampling
School Days
Sentence Beginning
Shore Features
Sound
Supermap
Synonyms
Systems of the Body
Teacher Create Series
Teacher Plus
Telling Time
The Basic Teacher Pac
The Earth and It's Composition
The Professional-Teaching Program
The Solar System
Transportation History
Typing
United States
Visual Perception Tests
Weather Fronts
Work Relationships
World Desert Region
World Polar Regions

FINANCE-INVESTMENT & PORTFOLIO ANALYSIS

Analysis I-Stock Trend Data Analysis
Commoapx System
Computicker
Computrac File Reader
Dow Jones News &
Quotes Reporter
Dow Jones Portfolio Evaluator
Dowlog-MC
Electronic Stock Package
Engineer's System For Trading
Forecast I
Forecast II
Fotofolio-Visual Display w/Statistics
Gann's Square of Nine Analysis
Intelligent Investor
Investment Analysis
Market Charter-Technical Analysis
Moneybee-Investment Analyst
Options 80-Stock Options Analyzer
Portfolio Master
Quotecharter
Quoteprocessor
Ratortn-Investment Analysis
Stock and Options Analysis
Stock Forecasting
Stock Market Management
Stock Market Utility
Stock Option Analysis
Stock Tracker
Stock Valuation Program
Stocksheets
Strategy M-Monitor Price Change
Dynamics
The Clover Method Trading System
The Stock Portfolio Program
Tickertec-Tickertape Program
Wilers 6 Systems Analysis

FOREIGN LANGUAGES

Chinese Lessons
Foreign Words and Phrases
Greek Roots and Prefixes
Japanese Lessons
Latin Roots and Prefixes
The French Hangman
The Russian Disk
The Spanish Hangman

GAMES

Adventures
Alien Rain
Alien Typhoon
Almanac — The Time Machine
Amaze
Analiza
Animal
Anti-Ballistic Missile
Apple Adventure
Apple Bowl
Apple Fun
Apple Panic
Apple Sack 3 — Adventure Pak
Apple Sack 7 — Space Sack
Apple Sack 8 — Game Sack
Apple Sack 9 — Base Star
Apple Stellar Invaders
Apple-oids
Asteron
Astro-Scope
Astrology
Autobahn
Backgammon 20
Battle of Midway
Beer Run
Best of Muse
Biorythms
Blackjack
Both Barrels
Brands
Bridge 2.0
Bridge Tutor
Bubbles, Planetoids and Burnout
Cartels and Cutthroats
Castle Wolfenstein
Chambers of Xenobia
Chebychev 1
Chebychev 2
Chronicles of Osgroth
Civil War
Compu-Math Arithmetic
Compu-Math Decimals
Compu-Math Fractions
Computer Air Combat
Computer Baseball
Computer Bismark
Computer Conflict
Computer Napoleonics
Computer Quarterback
Cops and Robbers
Cosmo Mission
County Carnival
Cyber Strike
Disk Talker
Dr. Chips
Dragon Fire
Dungeon
Executive Fitness
Falcons
Fantasyland 2041
Fastgammon
Flight Simulator
Galactic Attack
Galactic Wars
Galaxy Wars
Games People Play
Gamma Goblins
Gobbler
Golf/Cross-Out
Gorgon
Hammurabi
Head On Game
Hellfire Warrior
Hi-Res Football
Hi-Res Soccer
In The Army Now
Into Ships
Jet Fighter Pilot
Klondike 2000
Lost By Ship
Mastermind
Meteoroids in Space
Micro Othello
Mimic
Mind Games Package
Mission Asteroids
Mystery House
Need an Analyst
Nominees Jigsaw
Oil Tycoon
Olympic Decathlon
Operation Apocalypse
Orbitron
Outpost
Paddle Fun
Pegasus II
Perception 3.0
Phantoms Five
Planetoids
Plot 3D
Pokeno
Poker Slot Machine
Pool 1.5
Pot 'O Gold I
Pot 'O Gold II
President Elect
Pro Football
Pro Picks
Project Omega
Pulsar II
Race For Midnight
Raster Blaster
Red Baron
Rendezvous
Robot Wars
Sahara Warriors
Sargon II (Chess)
Satellite Trak
Shell Games
Shuffleboard
Skybombers
Skybombers II
Sneakers
Snoggle
Soft Porn
Softside Publications
Space Eggs
Space Warrior
Spellguard
Spelling Bee
Star Cruiser
Star Dance
Star Thief
Startraders
Startrek
Stock
Sub Attack
Tawala's Last Redoubt
Teacher's Pet
Temple of Apshal
Terrorist
Tetrad
The Strip
The Asteroid Field
The Great Escape
The Horse Selector II
The Prisoner
The Scorekeeper
The Shattered Alliance
The Warp Factor
Three Mile Island
Torpedo Fire
Ultima
Voyage of the Valkyrie
War and Games
War Games
Warp Factor
Watch Your Moves
Win at the Races
World's Greatest
Blackjack
Wumpus
Xplode

ME WHAT AN APPLE CAN DO?

GRAPHICS/ COMPUTER-AIDED DESIGN

3-D Surface Plotter Package
A2-3D1 Graphics Family
ABT Barwand Software
Action Sounds & Hi-Res Scrolling
Apple Plot
AppleGraphics II
Artist Designer
Bar Chart (Histogram) Graphics
Business Graphics III
Circuit Designer Graphics
Circuit Simulator
Creativity Tool Box
CURVFIT
Data Plot
E-Z DRAW
FLGDZINE
Graforth — Development Tool
Graph-Fit
Graph-Pak
GRAPHPOWER
Hi-Res Secrets
Line Graphics
MC Painting
ORIFICE
Pascal Animation Tools
Pascal Graphics Editor
Perspective Plot — 3-D Graphics
PGE — Graphics Editing Package
PILOT Animation Toolkit
Polar Coordinate Plot
RGL Real Time Graphic System
Screen Director
Shape Table Generator
Stats-graph
Super Shape Draw & Animate
Tablet Graphics
The Coloring Board Program
The Designer
Topographic Mapping
Ultra Plot
Utopia Graphics Tablet System
VACVESL — Vacuum Vessel Design
VESDZINE — Design of Vessels
VISITREND/VISIPLOT
X-Y Vector Plot Package

HOME MANAGEMENT

Address File
Auto Records
Checkbook Balancing
Checking Account Management
Chequemate
Diet Analysis
Financial Analyzer
Five Minute Financial Check-Up
Grocery List
Home Finance
Home Inventory File
Home Money Minder
Home Purchase Analysis
Magazine File
Mortgage Analysis
Personal Accounting System I
Personal Expense Record
Personal Finance Manager
Personal Financial Planning
Programmed Exercise
The Personal Check Manager

INCOME TAX

Dow Jones Portfolio Evaluator
Individual Tax Planner
Micro-Tax Individual Tax Package
Micro-Tax Integrated State Income Tax
Micro-Tax Partnership Package
SHORTAX — Tax Planning Package
Tax Planner
Tax Preparer
TRPS — Tax Return Preparation System

INVENTORY CONTROL

ARM-1000 — Rental Business
Basic Business Inventory
Bill of Materials
BPI Inventory Control
Intotory Inventory System
Inventory Accounting
Inventory Control
Inventory Management
Inventory Management for Stock Control
Inventory Pac
Inventory System Business Module
Manufacturing Inventory Control
MATSTAT-Materials Tracking
Order Entry/Inventory Control
Peachtree Inventory System
Point-Of-Sale Retail System
Property Manager for Moveable Equipment
Retail Inventory
Rogis Stock Control for Components
Stock Control
Stock Recording
Stockfile Inventory System
Stockroom Inventory and Purchasing
Structured Systems Inventory Control
TCS Inventory Management
The Order Scheduler

JOB & CONTRACT COST ACCOUNTING

Billflow
Bookkeeper II-Job Costing
BPI Job Costing
Contract Billing
Contractor Job Cost
Cost Accountant
Job Accounting System
Job Control System
Job Cost Accounting
Project Cost Accounting for Architects
Project Cost Accounting for Engineers
The Software Fitness Job Cost Analyst
Time Recording-Job Cost Analyst
Timerec-Transaction Carry Forward

MAILING LIST & LABEL PROCESSING

Address Book Mailing List
Apple III Mail List Manager
Apple Mail Sack
Apple Post
Benchmark Mail List
Commercial Mailer
Mail List
Mail80 Mailing List Software
MAILER-Name & Address Management System
Mailing Address
Mailing List Package
Mailing System
MAILMERGE
MAILPRO
Mailroom-Mailing List Management
Master Mailing List
NAD-Name & Address Selection System
Name And Address
Postmaster-Mail Management
Professional Mailout
School Mailer
Small Business Mailing & Filing
Super-M-List Mailing List Program
Ultra Plot/Mailing & Filing System I

MARKETING/SALES ANALYSIS

EASYTRAK-Salesmen Monitoring Package
Marketing Systems — Proposal Developer
Office and Agent Productivity Package
Sales Analysis
Sales Pro Prospect Mgt Package
Sales Tracker
SALESLOG — Sales Mgt Program
SNAP — Questionnaire Design and Printing
TCD Life Insurance Computer System

MISCELLANEOUS

BILL — Building Energy Use
Circuit Analysis
Hand Holding BASIC
Insulate
Mini-Warehouse System
Stepwise Multiple Regression

MUSIC

Alpha Syntauri Music Synthesizer
Apple Music Theory
Apple Sack Music & Graphics
Appleodion Music Synthesis System
Music System
Musicomp
The Electric Duet

ORDER ENTRY/ ACCOUNTS RECEIVABLE

BPI Accounts Receivable Program
Cash Receipts System
Company Sales
Invoice Compiler
Invoicing
Membership Billing
MICROREC
Multi-Property Accounts Receivable
Open Item Accounts Receivable
Order Entry
Order Entry and Billing
Order Entry and Invoicing
Order Tracking System
Peachtree Accounts Receivable
Peachtree Sales Invoicing
Progressive Billing
Purchase Order System
Receivables System Business Module
Receiver
Sales Invoicing
Sales Ledger
Sales Order Processing
Software Fitness Program — A/R System
Structured Systems Accounts Receivable
T-SOP Sales Order Processing
TCS Accounts Receivable Package
TCS Total Receivables
The Biller

PAYROLL PROCESSING

Advanced Payroll Package
After-The-Fact-Payroll — updates records
Apple Payroll System
Bookkeeper II-Payroll
BPI Payroll
Business Basic Payroll System
Contractor Payroll
Jobcost Payroll
Micropayroll
Passive Payroll
Paymaster
Paymaster-Payroll System
Payrecord I
Payroll
Payroll Accounting Package
Payroll Assistant
Payroll I
PeachPay
Piece Rate Payroll System
Post Facto Payroll
Print/Paycheck Accounting System
Run Time Payroll Program
Sheltered Workshop Reporting
Structured Systems Group Payroll
TCS Payroll Package
TCS Total Payroll
Variable Worker's Compensation
WH-347-Accessory program for Jobcost

PERSONNEL MANAGEMENT

AMI Post-Facto Payroll
MICROPERS — Payroll & Personnel Mgmt
Personnel Data Recorder
Personnel Office — Federal Compliance
Personnel Record
Personnel Record/Employee Records System

PROFESSIONAL OFFICE SYSTEMS

AMI Omegabyte Time & Billing
BETA — Stand Alone Time & Billing System
Billkeeper — Professional Billing
Client Billing System
Client Record/Bill Preparation
Datalaw System 3-Law Office Mgmt
DataTime
Dental 80A-Dental Accting & Billing
Dental Billing Package
Dental Office Management
DentalEase
Dentistaid — Dentist Office Management
Insyst (Insurance System)
Legal Billing & Timekeeping System
Legal Clerk — Office Management System
Legal Time Accounting System
Medicaid Day Treatment
Medical Accounting and Billing
Medical Clinic
Medical II — Office Mgmt System
Medical Office Management
Medical Secretary
Medical/Dental Management System
Medical/Manager
MedicalEase
MedPak
Medtips — Billing & Insurance Forms
PAS — 3-Patient Billing & Accts Receivable
Patient Accounting System
PIP-Payroll/Invoicing Program
Professional Office Management
Professional Time & Billing
PTA — Professional Time Accounting Pkg
Series 8000 Dental Mgmt
Series 8000 Medical Mgmt
Series 9000 Family Dental Management
The Patient Scheduler
Timeclock
Timemaster — Time Accounting
Timesaver Client Billing System

PROGRAMMING LANGUAGES

Ada Compiler
APL/V80 Language
Apple III Business Basic
Apple III Pascal
Apple FORTRAN
Apple Logo
Apple PILOT
ASM 65-Assembler
BASIC A+ — Extended Business Basic
BASIC Compiler
BASIC-80
BASIC/Z — Native Code Compiler
BD Software "C" Compiler
C Compiler
CBASIC 2 Compiler
CIS COBOL
COBOL 80
Cos Assembler
Cos COBOL
Focal 65-High Level Programming
Forth 86
Forth-Language Compiler
FORTRAN 80
FORTRAN IV
Hand Holding BASIC
KBASIC — Microsoft Disk Extended BASIC
Language System with Apple Pascal
LISP-80 Compiler
MAC 8080 Macro Assembler
MULISP Compiler
MULISP/MUSTAR 80
muMath/muSimp 80-High Level Programming
Nevada COBOL Compiler
Pascal Compiler
Pascal/M86
Pascal/MY+With SPP-ISO Standard
PL/1-80-Programming Language
RATFOR — FORTRAN Language
S-BASIC
SSS FORTRAN Compiler
Softronics
Stiff Upper Lisp
TCL Disk BASIC Interpreter
TCL-Pascal
TEC 65-Editing Language
Tiny BASIC High-Level Language
Tiny C
Tiny Pascal
Tiny-C-Two Compiler
Transforth II
UCSD Pascal
Whitesmith's Compiler
XPLO-Structured Language
XY BASIC Interactive Process Control

PROGRAMMING UTILITIES

Apple Sak 4 — Utility Package
Basic Utility Disk
Disk Utilities 3
Disk Utility Package
Disk-o-Tape-Pascal
DOS Tool Kit
File Maintenance Package
MAG/Sam Keyed File Mgmt System
MAG/Sort-Record Sort
Masterdisk-disk Sector Editor
MSORT — for COBOL 80
Pascal Utility Library
Pascal — Sort Program
PSORT — Pascal File Sorting
QSORT — Sort/Merge Program
SORT/B — Hybrid Sort
Supersort
Ultrasort

PURCHASING/ACCOUNTS PAYABLE

Accounting Payable
Accounts Payable Business Module
Accounts Payable/Purchase Order
Bookkeeper II — Accounts Payable
Cash Disbursements Posting System
Check Writer
Company Purchases
Contractor Accounts Payable
Disk-O-Check
Micropay-Accounts Payable
Print Check Accounting System
Purchase Ledger
Structured Systems Group Accts Payable
T-POP — Purchase Order Processing

REAL ESTATE

American Software Property Management
Apartment Building Investment Analysis
Apartment Manager
Commercial Property System
Construction Cost/Profit Analysis
Cornwall Apartment Management
Income Property Analysis
Listings
Multi-Property Accounting System
Office/Apartment Real Estate Management
Property Analysis System
Property Management
Property Management System
Property Mgmt — G/L Tenant and Expenses
Real Estate Analysis Program
Real Estate Analyzer
Realty Package
Rent vs. Buy
Rental Manager
Residential Property Management
Tax Deferred Exchange Model
Tenant Processing Package
The Landlord-Property Mgmt System
VisiCalc Real Estate Templates

TIME MANAGEMENT & SCHEDULING

Agenda Files
APM — Project Scheduling
Appointment Calendar
Color Calendar Package
Datebook Appointment Calendar
Datebook Time Management System
GUARDIAN — Computerized Scheduling
Office Manager — Staff Appointments
Personal Datebook
Professional Secretary
PROSCHED — Project Schedule
Time Manager

WORD PROCESSING

Apple World Oriented Text Editor
Apple Writer II
Apple Writer III
Benchmark — Word Processing System
Docuwriter Text Processor
Easywriter Word Processing
EDITRIX 1.0 — Word Processing
Form Letter Module
Formulex — Business Form Design
Goodspell
Letter Master — Basic Word Processor
Letteright Correspondence Processing
Letterite Word Processing System
Magic Spell — 20,000 Word Dictionary
Magic Wand — Phrase Insertion
Magic Wand — Word Processor
Magic Wand Word Processing System
Magic Window Word Processor
MAIL-MERGE-Wordstar Enhancement
Manuscripter — Word Processor
Master Text Processor
Memorite III Word Processing
Microspell Spelling Corrector
PALANTIR — Word Processing and Accounting
Personal Text Processing
Report Writer — Word Processing
Script III
Secretary — Word Processing
Spellbinder Word Processing
Spellguard
Super-Text Word Processing
Supertext II
TEXTWRITER III — Text Formatting Program
The Word Spelling Checker
VTS-80 CP/M Word Processing
WordIndex
WordMaster — Comprehensive Editor
Word Master Text Editor
WordStar — Word Processing

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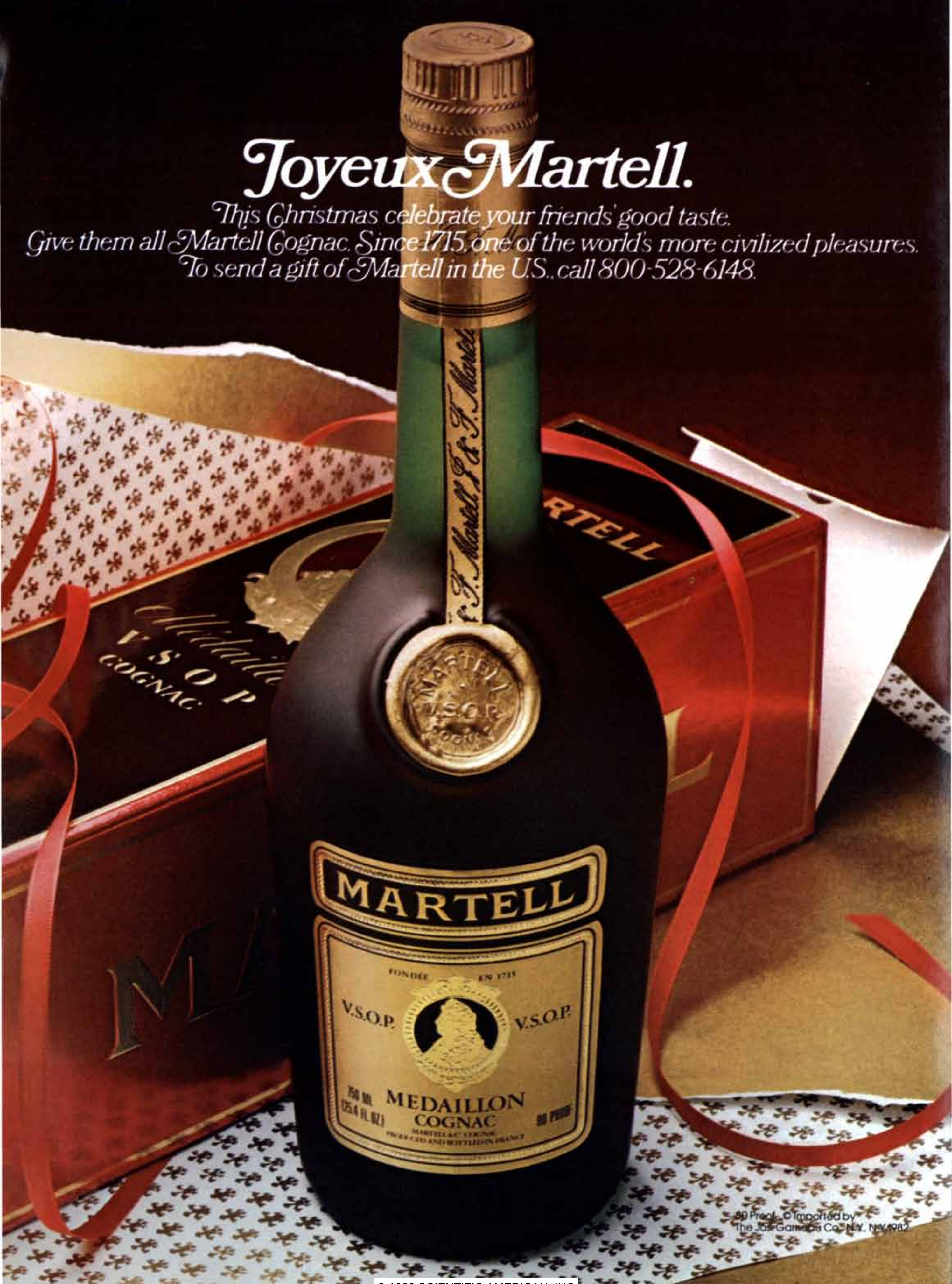
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ed. An answer has now been provided by a group of French educational psychologists. The results of their work, which appear in the journal *Cognition,* show that I. Q. scores can be raised at least 14 points by changing the social situation of the child at an early age. They conclude that a working-class child raised in an upper-middle-class household will have an I. Q. and a school record very similar to those of the biological children of upper-middle-class parents.

The authors, Michel Schiff, Michel Duyme, Annick Dumaret and Stanislaw Tomkiewicz, are on the staff of the French National Institute of Health and Medical Research (INSERM). The study compared children of working-class women who had been adopted by middle-class couples with other children of the same women who had been raised by their biological mothers. After sifting hundreds of adoption records the investigators found 35 children of 32 women who met the criteria of the study. All the mothers were from the lowest occupational group: unskilled workers. The children had been abandoned and had all been adopted before the age of six months. The foster parents were all from the upper 13 percent of the social and professional scale as indicated by the occupation of the husband.

Of the 32 women in the study, 20 had had other children who were not put up for adoption; these children, who had been raised in a working-class environment, made up the control group. The children of a particular woman did not necessarily have the same father. For any child to be included in the study, however, both parents had to have been unskilled workers.

The two groups of children of the working-class mothers were given several I. Q. tests when they were between about six and 13. In addition both groups were compared with large national samples of children of unskilled workers and children of upper-middle-class couples.

The observed differences between the adopted children and those reared by their biological mothers were striking. The mean score of the adopted children on the I. Q. tests was 109, almost exactly equal to the average of 110 scored by the upper-middle-class children in the national sample. Their siblings and half-siblings who had been raised in working-class households scored an average of 95, the same as the national sample of children of unskilled workers.

Moreover, the adopted children were about one-fourth as likely to fail in school as those who had been raised by the biological mother. Failure was defined in the study as having had to repeat a grade or having been put into a remedial class. The failure rates for both groups were almost identical with those for children of the social class in which the subjects had been raised.

The investigators note that studies such as the current one cannot settle the question of the relative importance of hereditary and environmental factors in determining intelligence, in part because the genetic makeup of the adopted children and the biological parents could not be rigorously controlled. Nevertheless, their results show the dramatic effect of the social environment on realized intelligence. They conclude that "if French children of lower-class parents were reared under exactly the same conditions as the adopted children of our study, they would obtain I. Q. scores and scholastic results close to those presently observed for upper-middle-class children. Our observations indicate that in the population at large [academic] failure is linked with the social class of the parents rather than with the genes they transmit."

The conclusion of the French workers contradicts the one Jensen arrived at. In his *Harvard Educational Review* article he argued that intelligence is determined primarily by hereditary factors. The environment exercises no more than a "threshold" effect: if the child has been much deprived in infancy, placing him in a richer environment can raise his I. Q. to the genetically determined potential, but enriching the environment further will not yield a corresponding gain in I. Q. According to Jensen, "children reared in rather average circumstances do not show an appreciable I. Q. gain as a result of being placed in a more culturally enriched environment.... I have found no report of a group of children being given permanently superior I. Q.'s by means of environmental manipulations. In brief it is doubtful that psychologists have found consistent evidence for any social environmental influences short of extreme environmental isolation which have a marked systematic effect on intelligence."

Beyond the Fringe

A faint telescopic image in the southern sky has been identified by a group of astronomers in Australia as the most distant known object in the universe. The 19th-magnitude light source, which was analyzed with the aid of the 153-inch Anglo-Australian Telescope at Siding Spring, coincides exactly with the position of a quasar, or quasi-stellar radio source, designated PKS 2000–330 at the time of its discovery in 1971. The relative distance of such an object is measured spectroscopically in terms of its red shift: the amount by which the wavelength of the radiation it emits is shifted toward the red end of the spectrum by virtue of the enormous velocity at which it is apparently receding from the earth. By this standard PKS 2000–330 has been found to have a red shift of 3.78. According to prevailing views of the expansion of the universe, a red shift of this value corresponds to a recession velocity of 92 percent of the speed of light; in other words, the radiation now reaching the earth from the quasar was emitted more than 15 billion years ago, only a few billion years after the big bang that initiated the expansion of the universe.

The previous record for the most remote celestial object was held for almost a decade by a quasar with a red shift of 3.53. The long-standing failure to detect a quasar with a greater red shift, in spite of repeated searches over the years by several different observational methods, lent support to an interesting speculation: Perhaps what was being seen at a maximum red shift of about 3.5 was the first appearance of quasars—or equivalently the edge of the observable universe. This view was reinforced by a recent series of optical surveys that should have been able to detect quasars with a red shift of more than 3.5, if indeed any were out there.

The identification of a quasar with a red shift of 3.78 does not invalidate the notion of a red-shift limit marking the edge of the observable universe; it can be interpreted as just extending the limit somewhat. Nevertheless, the concern remains that the apparent limit may have something to do with the methods employed to identify such objects. Writing in *The Astrophysical Journal,* the group responsible for the spectroscopic identification of PKS 2000–330 (Bruce A. Peterson, Ann Savage, David L. Jauncey and Alan E. Wright) cautions that "all surveys for QSO's [quasi-stellar objects] are beset with selection effects. Many of these selection effects, in both optical and radio surveys, can limit the red-shift range of the QSO's in the survey." High-red-shift objects similar to PKS 2000–330 should be found in the optical surveys, the group points out, but the narrow band of frequencies available to such surveys, together with variations in the sensitivity of the photographic emulsions employed, "will make it more difficult to recognize the nature of the high-red-shift objects and may account for the lack of identified QSO's with red shifts greater than 3.3 in these searches."

Rusty Core

The seismic waves that pass through the outer part of the earth's core indicate that it is a liquid with the properties of an alloy of molten iron. It is thought to be an alloy rather than pure iron because the seismological data also reveal that the density of the material is about 10 percent lower than the density of iron. What is the alloying element? A recent hypothesis, departing from the widely held view that it is sulfur, is that it is oxygen. If this can be demonstrated, it would have a bearing on hypotheses about how the earth was formed. The situation is reviewed in *Nature* by Raymond Jeanloz of the University of California at Berkeley.

The argument that the lighter material in the core is sulfur is largely based on the fact that outside the core sulfur is less abundant with respect to the other chemical elements than it is in the solar system as a whole, for example in meteorites or in the sun. In fact, in iron meteorites, which are presumably derived from the cores of shattered asteroids, sulfides are common. Moreover, laboratory experiments at high temperatures (but relatively low pressures) demonstrate that liquids consisting of iron and oxygen separate into immiscible iron-rich and oxygen-rich melts. In this view oxygen from the mantle of the earth would not be able to mix with the molten iron in the outer core.

The material of the outer core is at pressures ranging from 1.3 to 3.3 megabars (1.3 to 3.3 million times the atmospheric pressure at the surface of the earth) and temperatures ranging from 4,000 to 6,000 degrees Kelvin (degrees Celsius above absolute zero). If unusual chemical reactions can occur under those conditions, oxygen from the mantle might combine with the molten iron of the outer core to form an oxide. A. E. Ringwood of the Australian National University has been a leading exponent of the view that such chemical reactions can take place at the extreme conditions of the outer core.

Ringwood's hypothesis implies that the outer core, instead of being sharply different in composition from the mantle, as many other geochemists believe it to be, is in fact similar to the mantle. A requirement of this model is that the outer core formed at the high pressures existing deep within the earth after the earth had become a body of substantial size. Other models hypothesize that the core might have formed out of smaller metal-rich bodies in space before the rest of the earth's material accreted. Jeanloz writes: "There is no longer much doubt that compounds within the iron-oxygen system can exhibit marked changes in chemical properties at the pressures and temperatures of the earth's deep interior. To what extent these changes could decrease the miscibility gap between Fe [iron] and FeO [iron oxide] liquids is unknown."

Living Arrangements

The hindgut of the termite is proving to harbor some of the most spectacular examples of symbiosis in all nature. In the 1920's L. R. Cleveland of Johns Hopkins University established that certain wood-eating termites depend on intestinal protozoa to digest the cellulose in the wood the termites eat. In the absence of the protozoa the termite would eat wood but would starve. Then in the 1960's Cleveland, who was then at the University of Georgia, and A. V. Grimstone of the University of Cambridge showed that the protozoan *Mixotricha* is propelled about the hindgut of an Australian wood-eating termite not by its own flagella but by the coordinated undulation of symbiotic spirochetes arrayed on its surface.

Now the study of related protozoa in the hindgut of a Florida termite by Sidney L. Tamm of the Boston University Marine Program at the Marine Biological Laboratory in Woods Hole, Mass., reveals a still more unusual arrangement. These protozoans are called devescovinids (after a biologist named De Vescovi). Like *Mixotricha,* they digest cellulose. Moreover, they have bacteria arrayed on their surface. The bacteria propel the protozoans at speeds of up to 150 micrometers, or roughly the length of the organism, per second. What makes the arrangement unusual is that unlike the spirochetes on *Mixotricha* the bacteria on devescovinids do not undulate. Instead the protozoans are propelled by the hairlike flagella of the bacteria. Devescovinids are the only known case of a eukaryotic cell (a cell with a nucleus) propelled by the flagella of prokaryotes (cells without a nucleus).

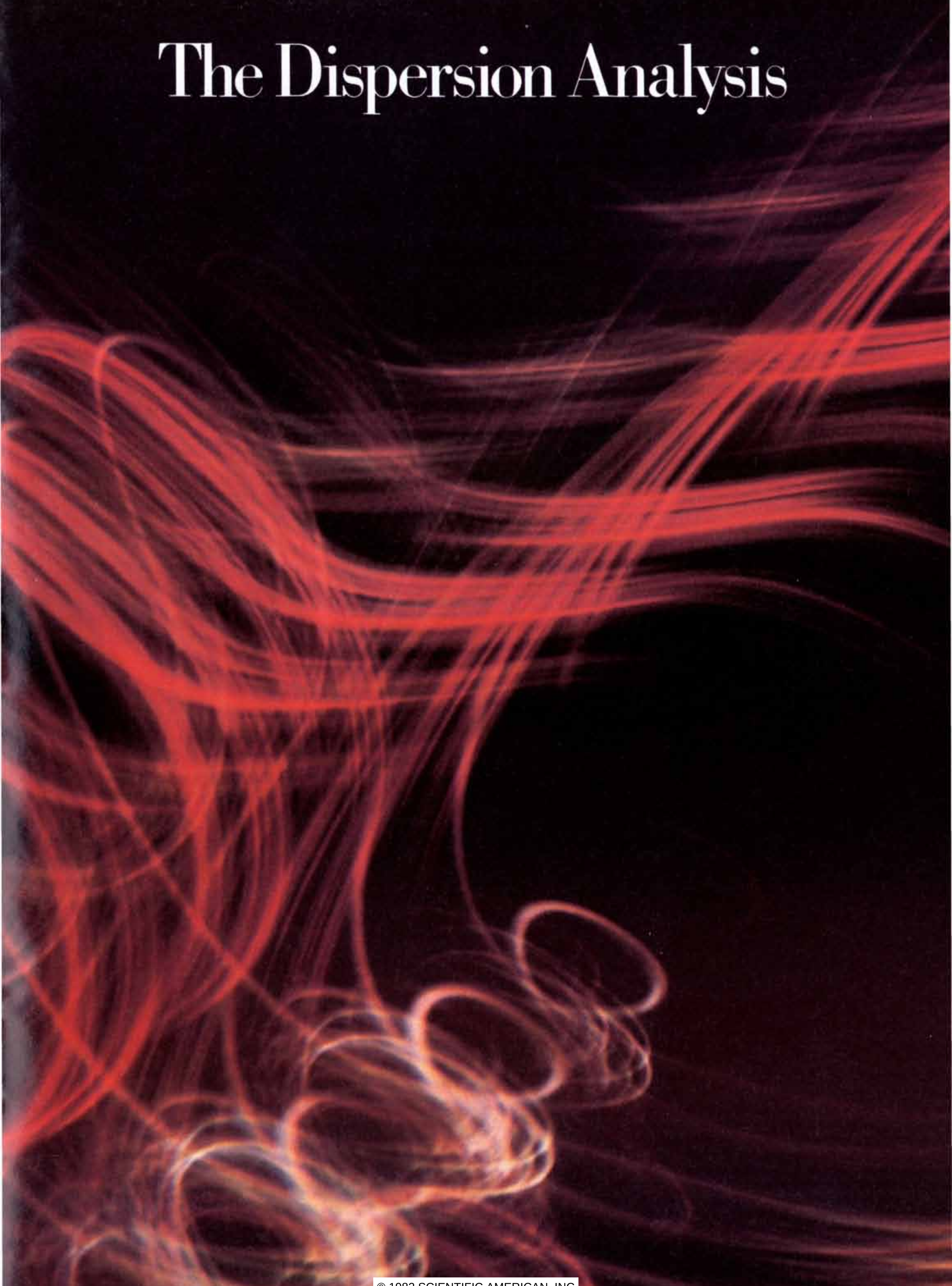
Tamm describes his research in *The Journal of Cell Biology.* Each devescovinid, he reports, is shaped like a zeppelin. At the front end of the cell are four flagella of the protozoan itself. They are about 30 micrometers long and whip about like typical eukaryotic flagella. The front end of the cell continuously rotates clockwise (as viewed from in front) with respect to the rest of the protozoan at speeds of up to one complete rotation every two seconds. The protozoan's outer membrane, however, is unbroken; "this motility," Tamm notes, "provides direct visual evidence for the fluid nature of cell membranes." Remarkably, devescovinids suspended in a fluid medium "display little or no net locomotion." Yet their front end continues to rotate and their flagella continue to beat, showing "that the protozoan's own motile systems do not propel it."

Attached to the surface of each devescovinid are several thousand bacteria. Some of them are rod-shaped and from two to three micrometers long. "They are arranged," Tamm writes, "end-to-end in parallel rows that follow a helical path over the body surface." The paths are interrupted only at the "shear zone" between the body and the rotating front end. Each of the rod-shaped bacteria has about 12 flagella. They are quite different from eukaryotic flagella: each one is a rigid, rotating helical filament about five micrometers long.

On a glass slide on the stage of a microscope Tamm has teased apart the hindgut of the termite. "The devescovinids vigorously slither through the seething mass" of their fellow protozoans. "Individual devescovinids move head first in tortuous paths at speeds of about 100 micrometers per second." They move, however, only when they are in contact with a surface: that of adjacent protozoans or of fragments of the gut. They also move when they are somewhat flattened between a slide and a coverslip. In the latter circumstance they "glide smoothly forward in fairly straight paths." Sometimes they "glide in circles or simply spin like wheels."

Tamm treated flattened devescovinids with antibiotics that are toxic to eukaryotic cells but have no effect on bacteria. The four flagella of each protozoan swelled up and "became completely inactive. Rotational movements of the [front] end of the cell usually stopped as well." The gliding and spinning continued. Then Tamm treated the flattened protozoans with a substance that saps the energy source of bacteria but has no effect on eukaryotes. The four flagella continued to beat and the front end continued to rotate, but the gliding and spinning stopped. A fortuitous discovery advanced the research. Pieces of the surface membrane of "extremely flattened" devescovinids became pinched off into vesicles (spherical sacs) that remained covered with rod-shaped bacteria. "The striking feature of these isolated parts of the devescovinid's surface is that they rotate constantly in the same direction.... Most significantly, the rotation speed of vesicles of similar size is related to the number of rod bacteria remaining on their surface."

How, then, do the rod-shaped bacteria propel the protozoan? A technique of microscopy in which individual bacteria on the surface of flattened devescovinids are examined under polarized light in a succession of video images that are processed electronically to enhance contrast shows dark and light bands traveling "away from [each] bacterial body like a rotating barber pole." The moving bands represent waves propagating along the length of a helical bundle formed by the flagella of the rod-shaped bacteria. Evidently the flagella of the bacteria that are lined up end to end along each given row on the surface of the protozoan overlap to form a single continuous strand of flagella rotating together. A cross section of the strand at any point must then include about 24 flagella. The waves in each strand move toward the back of the protozoan, which is thereby pushed forward. Tamm hypothesizes that devescovinids glide only when they are "in close contact with other cells or with a substrate" because the proximity "may bring adjacent flagella into common alignment for hydrodynamic reasons."


The Dispersion Analysis

The Dispersion Analysis

Exhaust dispersion near a roadway is influenced by the turbulence and heat generated by moving vehicles. Findings at the General Motors Research Laboratories have provided a new understanding of the dispersion process.

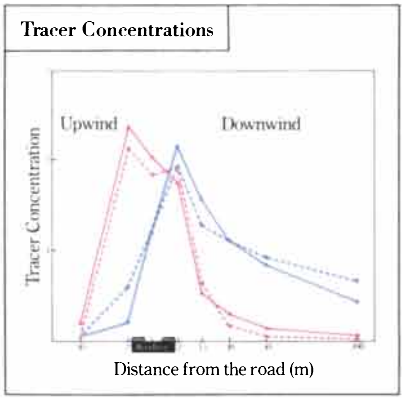


Figure 1: Observed (solid lines) and predicted (dashed lines) tracer concentrations near ground level as a function of distance from the edge of the road. Blue lines indicate the case in which the wind is perpendicular to the road; red lines, when the wind is nearly parallel to the road and opposing the upwind-lane traffic.

Figure 2: This representation of a roadway viewed from above shows the location of large vortices formed by local wind shear when the wind opposes the upwind-lane traffic.

BY USING the conservation-of-mass equation, one can describe the dispersion of gaseous molecules in the atmosphere. The equation includes terms for advection, diffusion, sources and sinks. Advection is the transport of air parcels by the mean wind; diffusion is due mainly to turbulent mixing. But the equation is useful only if we have information about the wind and temperature fields in the atmosphere. Specifically, our ability to predict vehicular exhaust concentrations near a road depends on knowledge of the effects of vehicles on these fields.

The conservation-of-mass equation for the mean concentration of any species, C, is

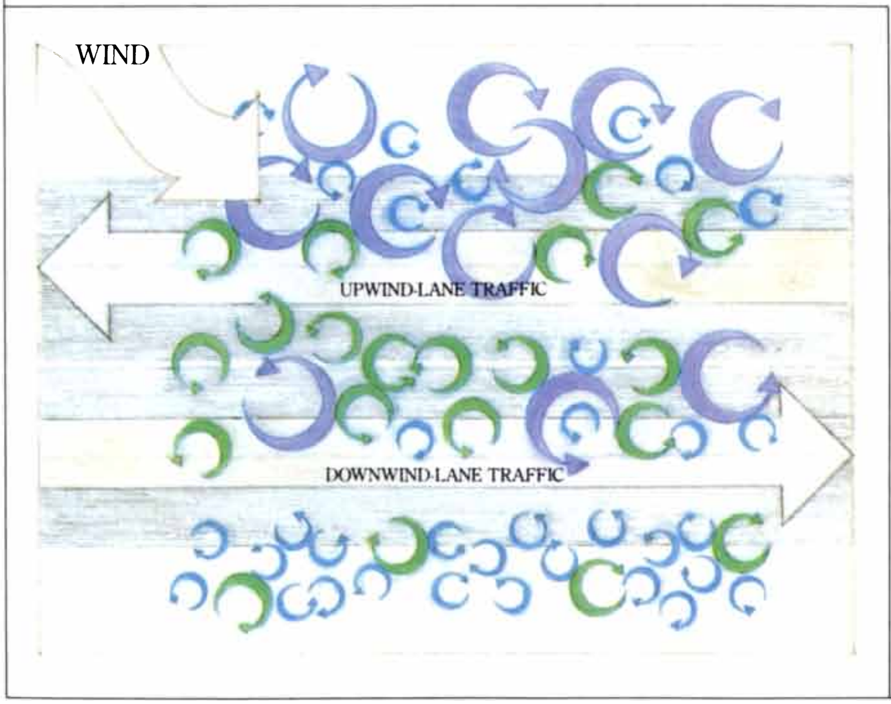
$$\frac{\partial C}{\partial t} + \sum_i \frac{\partial (U_i C)}{\partial x_i} = \sum_{i,j} \frac{\partial}{\partial x_i}\left(K_{ij}\frac{\partial C}{\partial x_j}\right) + So + Si$$

Local rate of change — Advection — Diffusion — Sources — Sinks

where U_i is the mean wind velocity and K_{ij} is the eddy diffusivity tensor. This equation applies when the length scale of mixing is small compared to that of the variation of the mean concentration. Near a road, this condition is met if the averaging time for the concentration and wind velocity is much longer than the time interval of vehicular passage. For a straight roadway, a long averaging time allows one to assume spatial uniformity in the direction parallel to the road, and to ignore the spatial derivatives in that direction.

The input information for K_{ij} and the mean crossroad and vertical wind components near a roadway became available as a result of a large-scale experiment conducted by the General Motors Research Laboratories. The experiment has provided an understanding of the influence of moving vehicles on mechanical turbulence and buoyancy near a roadway. Dr. David Chock was responsible for the design of the experiment and the analysis of the data. The experiment, which duplicated a heavily traveled, level roadway, was conducted under meterological conditions minimizing dispersion.

Moving vehicles affect the mean crossroad and vertical wind components in the following ways. Vehicles act as an obstacle to the mean wind, causing it to slow and move upward as it approaches the vehicles and downward as it leaves the road. In addition, vehicles release heat, which causes a net upward motion. It was established that the increase in the mean vertical wind component due to the exhaust heat was (B/U),[1,2] where U is the crossroad wind component.



The buoyancy flux, B, is proportional to the heat emission rate of the vehicles.

Moving vehicles also enhance both turbulence intensity and mixing. To determine how this modifies the eddy diffusivity tensor, K_{ij}, Dr. Chock invoked a "second-order closure" assumption, which relates eddy diffusivity to Reynolds stresses and the gradients of mean wind velocity and mean temperature. Eddy diffusivity was assumed to be the sum of ambient and traffic contributions. To determine the traffic contribution, the length scale of the traffic-induced turbulence was assumed to be comparable to vehicle height—1.5 m.

USING THE vast data base compiled during the experiment, Dr. Chock was able to specify K_{ij} and the mean crossroad and vertical wind components, and solve the equation numerically. To test the model, half-hour measurements of a tracer gas were used to map out experimentally the exhaust dispersion under various meteorological conditions. The case where the wind speed is low and the wind direction is nearly perpendicular to the roadway is represented by the blue lines in Figure 1. Both the model and the experiment show the same dispersion pattern. The peak concentration is on the downwind roadside.

When the wind is nearly parallel to the road, the situation is much more complicated. Figure 2 shows that when the wind and traffic flow on the upwind lanes oppose each other, a high shear region occurs immediately upwind of the first traffic lane. When the wind and traffic are in the same direction, the high shear region occurs in the median of the road. In these high shear regions, large eddies are generated and turbulent mixing is intense. The red lines in Figure 1 show a comparison of the model's predictions with the tracer data for the case illustrated by Figure 2. Notice that the peak concentration can actually occur on the upwind roadside, due to the exhaust transport by these large eddies. Dr. Chock's model is the first to predict this occurrence.

Under all combinations of wind speeds and directions, the predictions based on the model compare favorably with the measured tracer concentrations. There is little systematic bias with respect to wind direction.

"In light of this new model, exhaust dispersion near a roadway can now be predicted with reliability," says Dr. Chock. "This is of importance for environmentally sound road planning, and opens the door to the investigation of dispersion on city streets, where the presence of tall structures introduces even further complexity."

THE MAN BEHIND THE WORK

Dr. David Chock is a Senior Staff Research Scientist in the Environmental Science Department at the General Motors Research Laboratories.

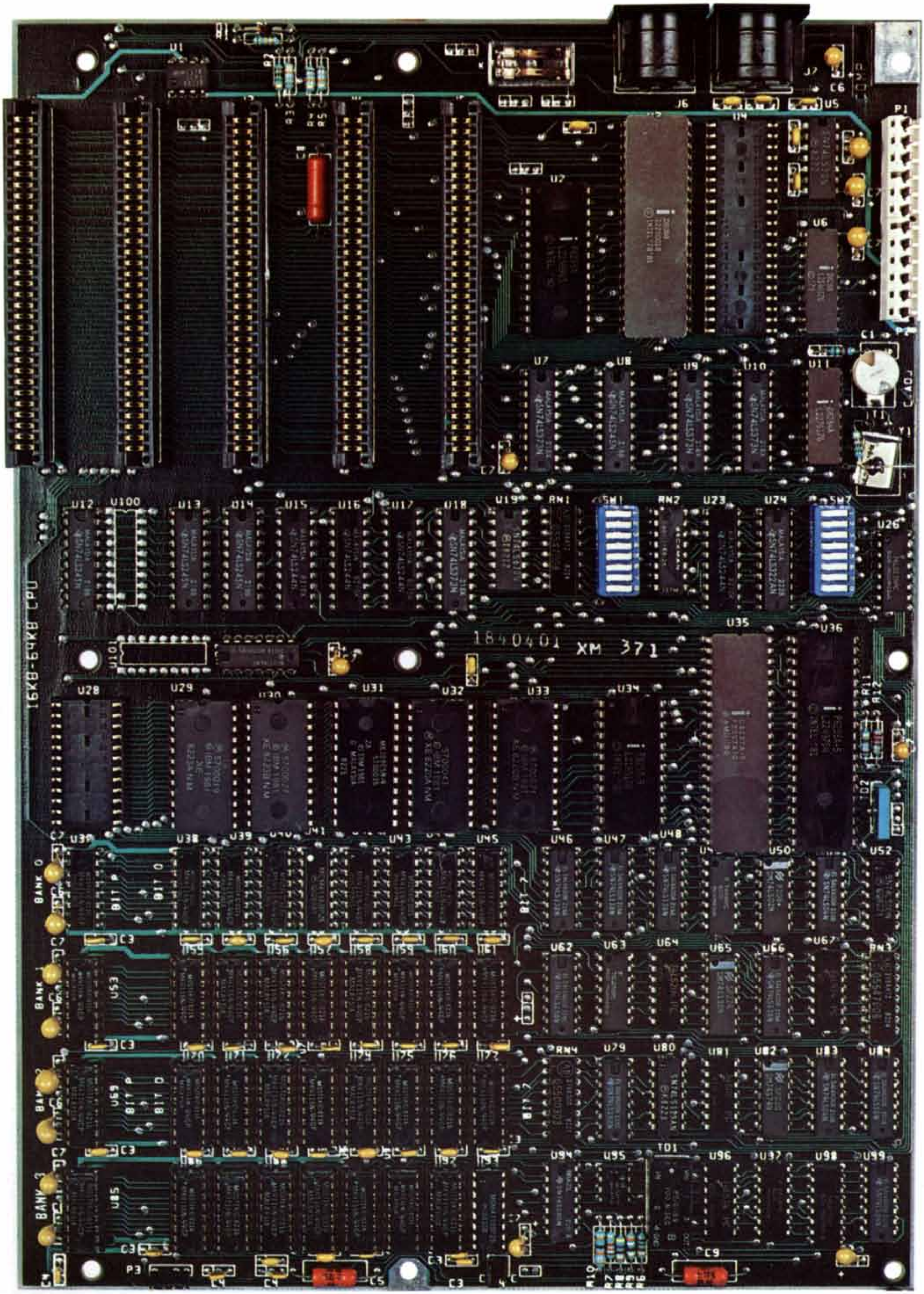
Dr. Chock received his Ph.D. in Chemical Physics from the University of Chicago. His thesis concerned the quantum mechanics of molecules and molecular crystals. As a Postdoctoral Fellow at the Free University of Brussels, he did research work on the dynamics of critical phenomena. He did additional postdoctoral work in the fields of solid-state physics and fluid dynamics.

Dr. Chock joined the corporation in 1972. He is leader of the GM atmospheric modeling group. His current research interests include the phenomena of atmospheric transport and reactions, and the statistical study of time-series data.

General Motors

GM

MARK OF EXCELLENCE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Personal Computers

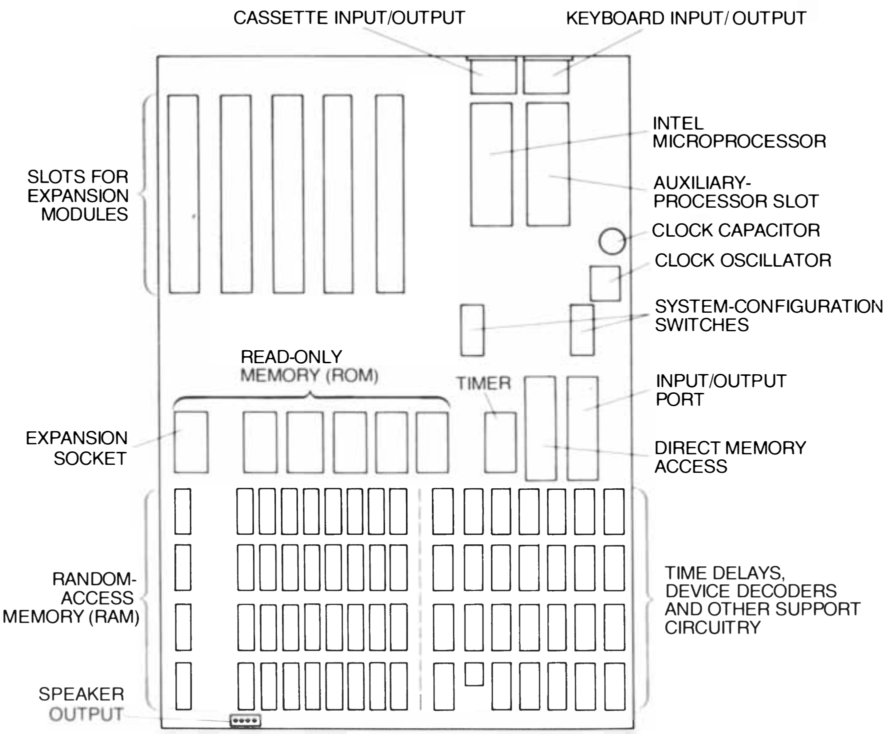
An account of their hardware, software, applications and current proliferation. By making computers accessible to untrained people they promise to bring about the long-heralded computer revolution

by Hoo-min D. Toong and Amar Gupta

If the aircraft industry had evolved as spectacularly as the computer industry over the past 25 years, a Boeing 767 would cost $500 today, and it would circle the globe in 20 minutes on five gallons of fuel. Such performance would represent a rough analogue of the reduction in cost, the increase in speed of operation and the decrease in energy consumption of computers. The cost of computer logic devices is falling at the rate of 25 percent per year and the cost of computer memory at the rate of 40 percent per year. Computational speed has increased by a factor of 200 in 25 years. In the same period the cost, the energy consumption and the size of computers of comparable power have decreased by a factor of 10,000.

The result is the advent of the personal computer, which for less than $500 can put at the disposal of an individual about the same basic computing power as a mainframe computer did in the early 1960's and as a minicomputer did in the early 1970's. Twenty years ago the cost of a computer could be justified only if the machine met the needs of a large organization. The minicomputers introduced in the 1970's are appropriate for a department or a working group within such an organization. Today the personal computer can serve as a work station for the individual. Moreover, just as it has become financially feasible to provide a computer for the individual worker, so also technical developments have made the interface between man and machine increasingly "friendly," so that a wide array of computer functions are now accessible to people with no technical background.

The first personal computer was put on the market in 1975. By the end of this year more than a million personal computers will be in service in the U.S. alone. In 1981 total sales of personal computers and their accessories in the U.S. amounted to $2.2 billion; sales are expected to surpass $6 billion in 1985. There has been talk of a "computer revolution" ever since the electronics industry learned in the late 1950's to inscribe miniature electronic circuits on a chip of silicon. What has been witnessed so far has been a steady, albeit remarkably speedy, evolution. With the proliferation of personal computers, however, the way may indeed be open for a true revolution in how business is conducted, in how people organize their personal affairs and perhaps even in how people think.



MAIN CIRCUIT BOARD of the IBM Personal Computer is shown in the photograph on the opposite page and its major elements are identified in the drawing above. The size of the board is $8\frac{1}{2}$ by 12 inches. To it are attached a large number of silicon chips carrying integrated circuits; each chip is about a quarter of an inch square and is encased in a rectangular plastic package fitted with electrodes. The chips and elements such as resistors and capacitors are interconnected by conductors printed on the board. The microprocessor, the 16-bit 8088 made by the Intel Corporation, has 20,000 transistors and operates at a frequency of almost five million cycles per second. "System programs" are stored permanently in the read-only memory (ROM); random-access memory (RAM) stores programs and data that change from time to time.

Anatomy of a Computer

A computer is essentially a machine that receives, stores, manipulates and communicates information. It does so by breaking a task down into logical operations that can be carried out on binary numbers—strings of 0's and 1's—and doing hundreds of thousands or millions of such operations per second. At the heart of the computer is the central processing unit, which performs the basic arithmetic and logic functions and supervises the operation of the entire system. In a personal computer the central processing unit is a microprocessor: a single integrated circuit on a chip of silicon that is typically about a quarter of an inch on a side. Other silicon chips constitute the computer's primary memory, where both instructions and data can be stored. Still other chips govern the input and output of data and carry out control operations. The chips are mounted on a heavy plastic circuit board; a printed pattern of conductors interconnects the chips and supplies them with power. The board is enclosed in a cabinet; in some instances there are several boards.

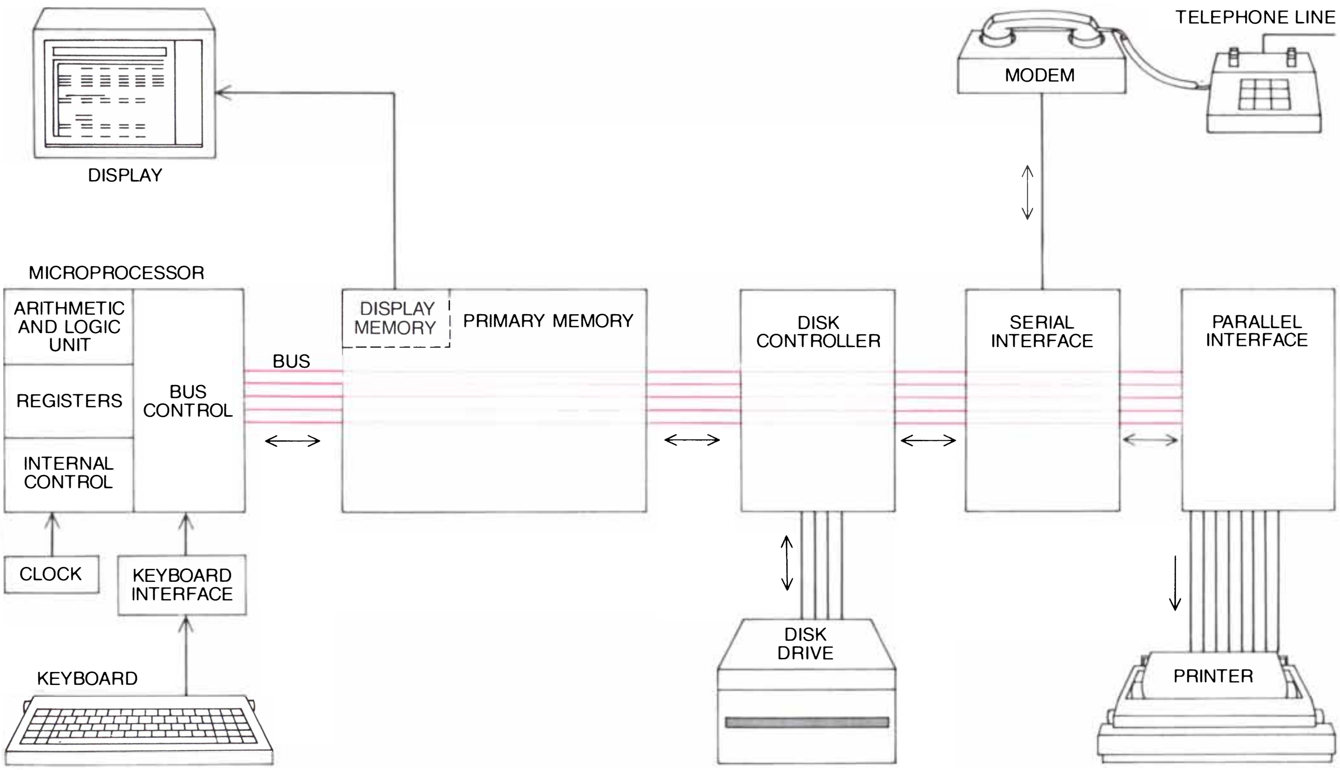
Information is entered into the computer by means of a keyboard or is transferred into it from secondary storage on magnetic tapes or disks. The computer's output is displayed on a screen, either the computer's own cathode-ray tube, called a monitor, or an ordinary television screen. The output can also be printed on paper by a separate printer unit. The device called a modem (for modulator-demodulator) can be attached to convert the computer's digital signals into signals for transmission over telephone lines.

The chips and other electronic elements and the various peripheral devices constitute the computer's hardware. The hardware can do nothing by itself; it requires the array of programs, or instructions, collectively called software. The core of the software is an "operating system" that controls the computer's operations and manages the flow of information. The operating system mediates between the machine and the human operator and between the machine and an "application" program that enables the computer to perform a specific task: solving a differential equation, calculating a payroll or editing a letter. Programs are ordinarily stored in secondary-memory media and are read into the primary memory as they are needed for a particular application.

The Personal Computer

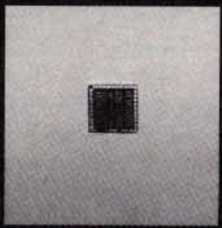
A personal computer is a small computer based on a microprocessor; it is a microcomputer. Not all microcomputers, however, are personal computers. A microcomputer can be dedicated to a single task such as controlling a machine tool or metering the injection of fuel into an automobile engine; it can be a word processor, a video game or a "pocket computer" that is not quite a computer. A personal computer is something different: a stand-alone computer that puts a wide array of capabilities at the disposal of an individual. We define a personal computer as a system that has all the following characteristics:

1. The price of a complete system is less than $5,000.
2. The system either includes or can be linked to secondary memory in the form of cassette tapes or disks.
3. The microprocessor can support a primary-memory capacity of 64 kilobytes or more. (A kilobyte is equal to 2^{10}, or 1,024, bytes. A byte is a string of eight bits, or binary digits. One byte can represent one alphabetic character or one or two decimal digits. A 64-kilobyte memory can store 65,536 characters, or some 10,000 words of English text.)
4. The computer can handle at least one high-level language, such as Basic, Fortran or Cobol. In a language of this kind instructions can be formulated at a fairly high level of abstraction and without taking into account the detailed operations of the hardware.
5. The operating system facilitates an interactive dialogue; the computer responds immediately (or at least quickly) to the user's actions and requests.
6. Distribution is largely through mass-marketing channels, with emphasis on sales to people who have not worked with a computer before.



HARDWARE OF A PERSONAL COMPUTER includes devices for processing and storing information and for communicating with the user and with other electronic devices. A set of parallel conductors called a bus (*color*) connects the main components. The processing unit, which generally includes not only the microprocessor chip itself but also various auxiliary chips, carries out essentially all calculations and controls the entire system. Information can be entered into the system through a keyboard. Pressing a key generates a coded signal unique to that key; the code is stored in the display memory and so appears on the cathode-ray-tube display. The primary memory, which consists of semiconductor memory chips, holds programs and data currently in use; it is a random-access memory, meaning that the content of any cell can be examined or changed independently of all the other cells. Disk storage generally has a larger capacity than the primary memory, but it is slower and its information is recovered in larger blocks. The interfaces connect the computer to other devices, such as a printer or a modem (which gives access to other computers through the telephone system). In a serial interface information is transferred one bit at a time; in a parallel interface multiple conductors carry several bits (in most instances eight) at a time.

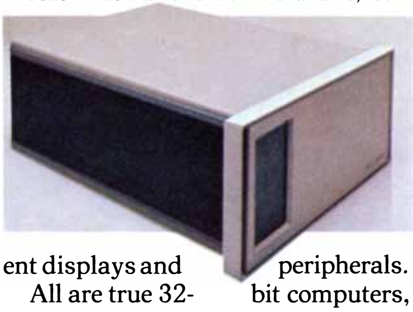
In 1981, Hewlett-Packard announced the world's densest computer chip.



Our 450,000-transistor, one-chip 32-bit CPU.

Today, it's the heart of a 32-bit co that's so affordable your top enginee can have their own mainframes.

A rack-mountable version is available, too.



From time to time, miracles of technology come along to make previously impossible tasks not only possible, but easy. That little integrated circuit chip on the preceding page is one of those technological miracles.

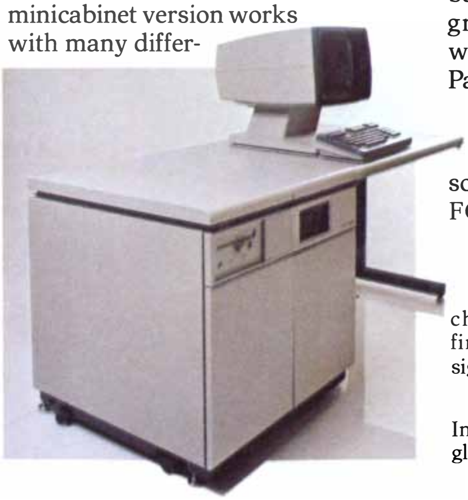
Hewlett-Packard didn't develop it just to break the record for most transistors on a chip, but to put on an engineer's or scientist's desk a computer so powerful that it can do the work of mainframes costing four times as much.

32-bit computers for 32-bit applications.

The new HP 9000 computer based on this and four other 'superchips' can handle formidable engineering and scientific problems. The scientist solving complex systems of equations, the mechanical engineer doing finite element analysis or three-dimensional modeling, the electrical engineer analyzing complex circuits or designing very large-scale integrated circuits—these are the kinds of technical people and problems the HP 9000 family is designed for.

It comes in three versions. The integrated workstation is complete with keyboard, color or monochromatic graphics display, fixed and flexible disc drives, and printer. For systems manufacturers, there's a rack-mountable box. And for a variety of single-user and multi-user applications, the minicabinet version works with many different displays and peripherals.

All are true 32-bit computers, with 32-bit CPUs, memories, and data paths. And the multi-CPU architecture lets you nearly double or triple your processing power at any time by adding one or two CPU boards. Without increasing the computer's size.



As a minicabinet, it can handle multiple users.

Two operating systems are better than one.

The integrated workstation is available with a choice of operating systems. One is HP's highly evolved, high-performance Enhanced BASIC, augmented with 3-D graphics and a software innovation called a run-time compiler. This substantially increases program execution speed, while retaining an interactive development environment.

The other operating system, called HP-UX, is a fully supported, extended version of the popular UNIX.® HP-UX, available on all HP 9000s, adds virtual memory, graphics, data base management, data communications, and enhanced file capability to the basic UNIX 'shell.' High-level programming languages available with HP-UX are FORTRAN 77, Pascal and C.

Software, and plenty of it.

Much of the vast range of existing software written in HP BASIC, FORTRAN 77, Pascal and C is transportable to the HP 9000. HP will also be offering proprietary software packages emphasizing computer-aided design and engineering. These will tie the HP 9000 into HP's Manufacturer's Productivity Network (MPN). Third-party software suppliers will be providing many of the most widely used CAE packages for 32-bit computer systems. And both HP 9000 operating

The 32-bit CPU chip is bonded to the finstrate which doubles as a signal carrier and heat sink.

Up to three CPU boards and three Input/Output Processors can fit into a single HP 9000.

TCG-207

.nputer
rs and scientists

systems offer extensive program development tools.

You also get a choice of communication tools. The HP 9000 is currently compatible with Ethernet,™ and with HP's Shared Resource Manager (SRM) which lets clusters of HP 9000 and 16-bit desktop computers share data and use common peripherals. Links to central computers are also available. And in late 1983, HP will offer local area networks based on the IEEE-802 standard.

New technology from the silicon up.

The five superchips that make the HP 9000 possible are the 32-bit CPU, which can execute a million instructions per second; an eight-channel Input/Output processor (IOP); a random-access memory chip capable of storing 128K bytes of data; a memory controller that 'heals' up to 32 bad memory locations; and an 18-megahertz clock.

Hewlett-Packard's advanced NMOS-III process makes it possible to put 450,000 transistors on a chip only 0.4 centimeters square. This tremendous density of electronic components could have required an expensive and elaborate cooling system.

Instead, HP engineers developed a new mounting structure called a finstrate, a copper-cored circuit board, which acts as both cooling fin and substrate. The finstrates containing the CPU, IOP, memory, and clock chips are housed in a lunchpail-sized module.

One user, one mainframe.

Clearly the trend in engineering and scientific computation is away from large machines shared by multiple users and towards networks of powerful personal workstations, sharing peripherals and data bases. The reason is compelling. An engineer or scientist in personal control of an HP 9000 can solve so many more problems more easily that the increased productivity alone makes the cost of individual computers easy to justify.

For complete information about this powerful breakthrough in 32-bit computing, contact the local HP sales office listed in your telephone directory. Ask a Technical Computer Specialist for a demonstration. Or write to Pete Hamilton, Dept. 56151, Hewlett-Packard, 3404 East Harmony Road, Fort Collins, CO 80525.

HEWLETT PACKARD

UNIX is a registered trademark of Bell Laboratories. Ethernet is a trademark of Xerox Corporation.

7. The system is flexible enough to accept a wide range of programs serving varied applications; it is not designed for a single purpose or a single category of purchasers.

The definition will surely change as improved technology makes possible—and as the marketplace demands—the inclusion of more memory and of more special hardware and software features in the basic system. Having defined a personal computer, of necessity somewhat arbitrarily, we shall now describe its essential components in some detail.

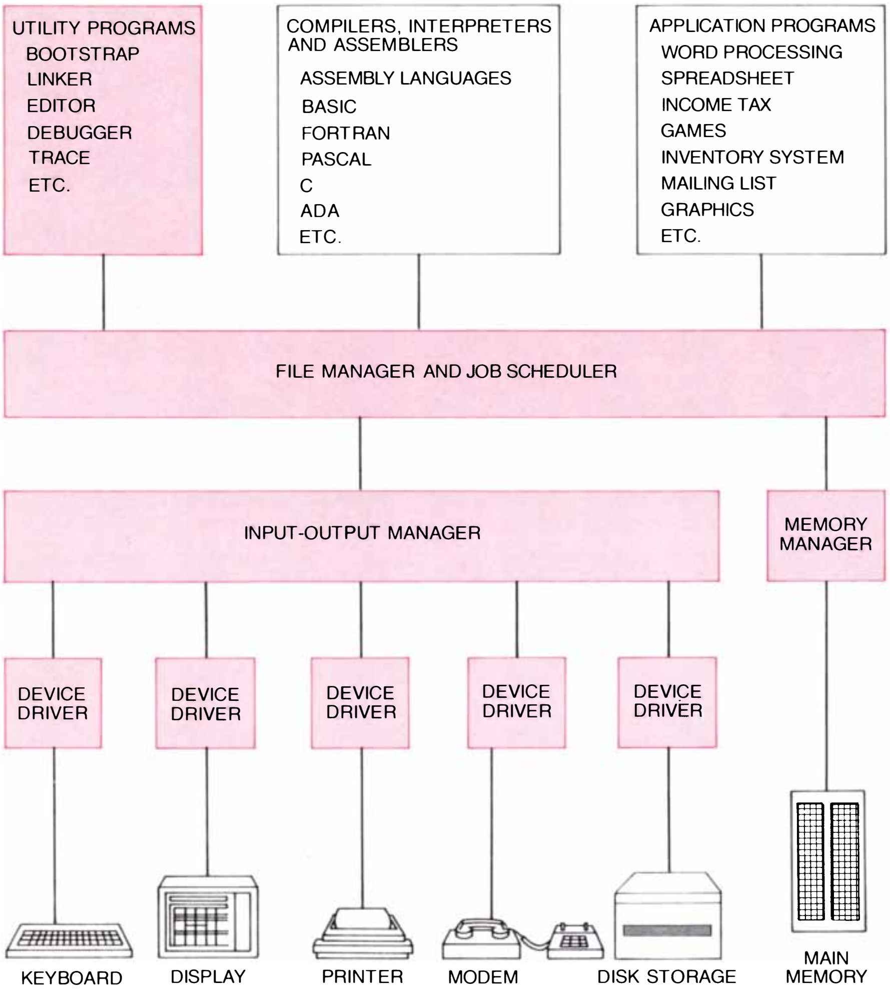
Microprocessor and Memory

Two major determinants of the computational power of a microprocessor are its word size, which governs the "width" of the computer's data path, and the frequency of its electronic clock, which synchronizes the computer's operations. The trend in microprocessors is toward a larger word size and a higher frequency. As the word size increases, an operation can be completed in fewer machine cycles; as the frequency increases, there are more cycles per second. In general a larger word size also brings the ability to access a larger volume of memory. The first generation of true personal computers, which came on the market between 1977 and 1981, had eight-bit microprocessors; the most recently introduced systems have 16-bit ones. Now 32-bit microprocessor chips are available, and soon they will be included in complete computer systems. Today an eight-bit chip costs $5, a 16-bit chip costs $50 and a 32-bit chip costs $250. As improved technology lowers costs more personal computers will come to have 32-bit processors. Until perhaps 1985, however, a 16-bit word size will probably be standard. As for clock frequency, the trend has been from one megahertz (one million cycles per second) a few years ago to 10 megahertz or more today.

There are two kinds of primary memory: read-only memory (ROM) and random-access memory (RAM). Read-only memory is for information that is "written in" at the factory and is to be stored permanently. It cannot be altered. For a single-application computer such as a word processor the information in ROM might include the application program. In the case of a versatile personal computer it would include at least the most fundamental of the "system programs," those that get a computer going when it is turned on or interpret a keystroke on the keyboard or cause a file stored in the computer to be printed. As the cost of ROM drops there has been a tendency among manufacturers to include more and more system programs in ROM rather than on secondary-storage media.

Random-access memory is also called read/write memory: new information can be written in and read out as often as it is needed. RAM chips store information that is changed from time to time, including both programs and data. For example, a program for a particular application is read into RAM from a secondary-storage disk; once the program is in RAM its instructions are available to the microprocessor. A RAM chip holds information in a repetitive array of microelectronic "cells," each cell storing one bit. The density of commercially available memory chips, that is, the number of bits per chip, has increased by a factor of 64 over the past decade, with a resulting 50-fold reduction in the cost per bit. Five years ago a single RAM chip stored no more than 16 kilobits (16,384 bits); now several personal computers have 64-kilobit chips, and by 1984 the 256-kilobit chip is expected to be widely available.

Even though the individual memory chip is an array of bits, information is generally transferred into and out of primary memory in the form of bytes, and the memory capacity of the computer is measured in bytes. A typical personal computer comes with a RAM capacity of between 16 and 64 kilobytes, which can be expanded by the addition of extra memory boards, or modules. In general it is a good rule to buy a system that has at least enough memory to accommodate the largest application program one expects to execute. Most off-the-shelf program packages carry an indica-



SOFTWARE OF THE COMPUTER is centered on the operating system (*color*), a set of programs that manage the computer's resources, supervise the storage of programs and other information and coordinate the various tasks. Application programs are those that carry out some function at the user's direction. In principle an application program could be designed to run without an operating system, but it would have to include detailed instructions for the allocation of storage space both in the primary memory and on disks and for operating all the peripheral devices associated with the computer. These tasks are taken over by the operating system. Programs must be in "machine language" (a string of binary digits) in order to be executed. The necessary translation is done by programs called assemblers, compilers and interpreters. Assemblers and compilers translate an entire program before it is run; interpreters translate each instruction in turn as the program is being run. Various utility programs, which are sometimes considered part of the operating system, can assist the user in writing or running other programs. A "bootstrap" program, for example, supplies the initial instructions when the computer is first turned on, and a trace program allows the state of the system to be examined.

tion of the minimum memory required.

The standard medium for secondary storage is the floppy disk: a flexible disk of Mylar plastic, now either $5\frac{1}{4}$ or eight inches in diameter, coated on one side or both sides with a magnetic material. Information is stored in concentric tracks of minute magnetized regions; changes in the direction of magnetization represent binary 0's and 1's. The information is written onto the disk and retrieved from it by a recording head that is moved radially across the spinning disk to a particular track. The track in turn is divided into a number of sectors, and as a rule information is written or read one sector at a time. Depending on the particular format there are between eight and 26 sectors per track and each sector holds from 128 to 512 bytes of data. The total storage capacity of a floppy disk varies according to the density of the data stored along a track (as high as 7,000 bits per inch), the density of the concentric tracks (as high as 150 tracks per radial inch) and the number of segments into which each track is divided. Most floppy disks now have a capacity of from 125 to 500 kilobytes; disks of higher density are beginning to be available.

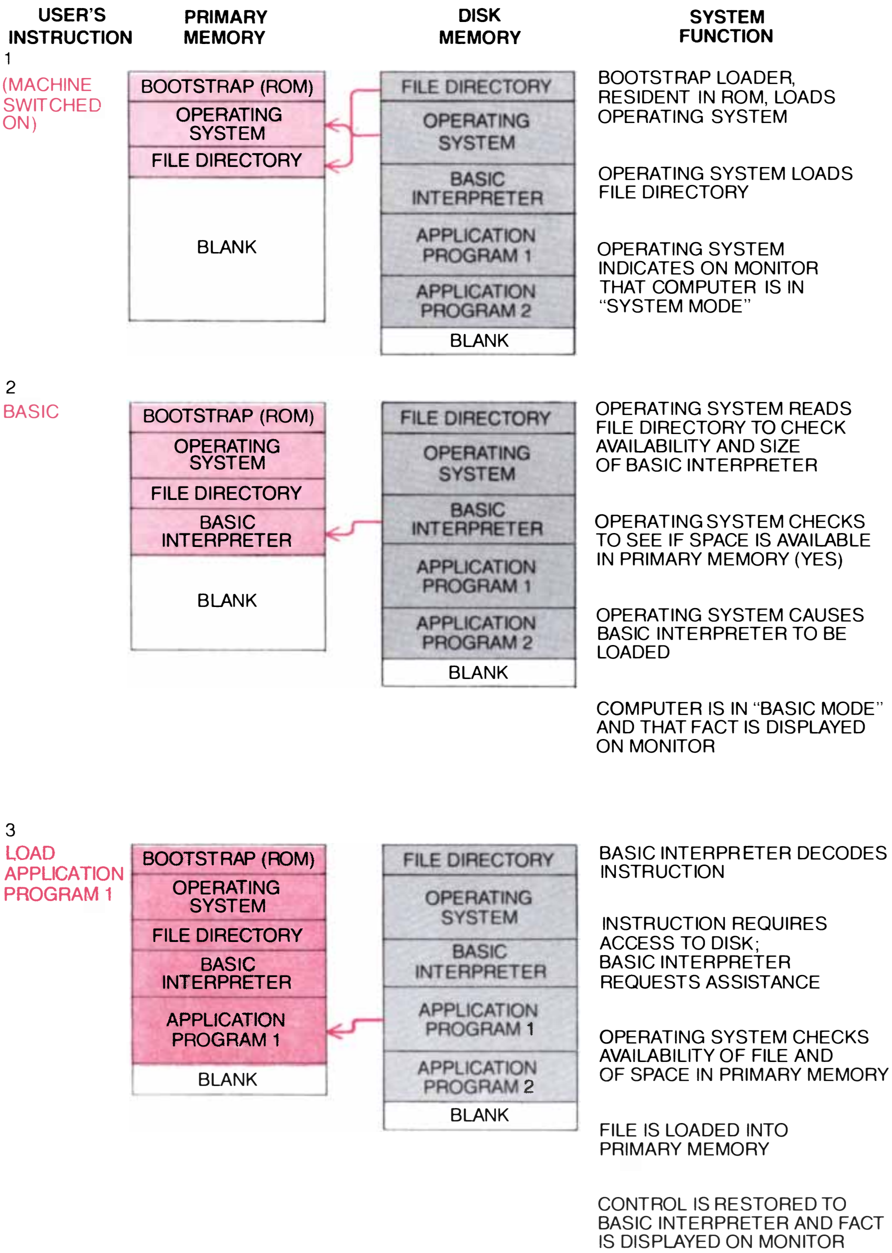
A more expensive alternative to the floppy disk is the Winchester disk, in which the magnetic coating is applied to a rigid aluminum platter. A personal-computer Winchester disk unit can have a capacity of from five to 50 megabytes (millions of bytes), and it can transfer data faster than a floppy disk. On the other hand, the Winchester disk is permanently sealed in the drive unit, whereas a floppy disk can be removed from the drive and replaced by a fresh disk.

A simpler, less expensive secondary-memory medium is the audio magnetic-tape cassette. One cassette can store about as much information as a relatively low-capacity floppy disk. The access time to a particular address, or storage location, is much longer for tape than it is for a disk because the speed of the tape is much lower than that of a disk and because the information is arrayed in a single linear sequence. An important feature of all the magnetic secondary-storage mediums is that information is maintained even when the computer is turned off.

Output

The primary output medium for a personal computer is a visual display, usually on a cathode-ray tube: either a monitor supplied with the computer or the purchaser's own television screen. Flat-panel displays that exploit liquid-crystal or gas-discharge technology are beginning to be competitive, particularly for small, portable systems. The character images needed for the display of text are stored as patterns of dots in a special ROM called a character generator. The clarity of the text depends on the number of dots employed in forming each character. A typical monitor can display 24 lines of text, each line of which has a maximum of 80 characters.

The display of graphic images, whether they are engineering drawings, graphs or moving targets in a video game, calls for complex software and for large amounts of memory. A detailed drawing or a smooth curve on a graph requires a high-resolution image. Resolution is determined by the number of pixels (picture elements) that can be addressed by the computer. A 280-by-192-pixel image in black and white fills more than 50 kilobits of RAM capacity, whereas a 128-by-48 image needs only about six kilobits. Many personal computers can generate images in color, which can raise the memory requirement by a factor of four or more. A high-resolution image, particularly one



FUNCTIONS OF THE OPERATING SYSTEM are illustrated by the successive events required to load an application program. Switching the computer on (*1*) actuates a bootstrap program that loads the operating system into the primary memory. The operating system transfers a file directory from the disk memory to the primary memory; in the file directory is listed the address, or position, of every program and data file recorded on the disk. In response to the next instruction (*2*) the operating system finds the Basic interpreter on the disk and, after making certain there is enough space for it, loads it into the primary memory; the user is notified that the interpreter is ready. (Some personal computers perform step *2* automatically as part of the switching-on sequence.) The operating system is called on to load the application program itself (*3*). Now, with the interpreter again in control, the application program can be run. Output will be new data file in primary memory, which can be transferred to disk storage.

in color, can be displayed clearly only on a monitor.

For many purposes a printed copy of the computer's output is desirable. There are a number of different kinds of printer, which vary widely in price, speed and the quality of the text they turn out. Thermal printers, which cost less than $500, burn an image into a special paper at a rate of some 50 characters per second. Dot-matrix printers cost between $400 and $1,500 and can be very fast: as many as 200 characters per second. An array of from five to 18 tiny wires is swept across the paper. Signals from the computer drive the wires against an inked ribbon, leaving a pattern of dots on the paper. The quality of the characters thus formed depends largely on the size of the dot matrix available for each character; the array of dots is commonly either five by seven or seven by nine. With suitable control programs and enough memory capacity the dot-matrix printer can generate graphic images in black and white or in color.

Most thermal and dot-matrix printers generate text that is readable but hardly elegant. "Letter quality" printing calls for more expensive devices more closely related to a typewriter. One such device is the daisy-wheel printer, which costs at least $750 and can print up to 55 characters per second. The printing head is a rotating hub with 96 radial arms or more, each arm carrying a letter or other character. As the daisy wheel moves across the paper, signals from the computer spin the wheel and actuate a hammer that drives the proper arm against the inking ribbon.

Software

Although the hardware of a computer ultimately determines its capacity for storing and processing information, the user seldom has occasion to deal with the hardware directly. A hierarchy of programs, which together constitute the software of the computer, intervenes between the user and the hardware.

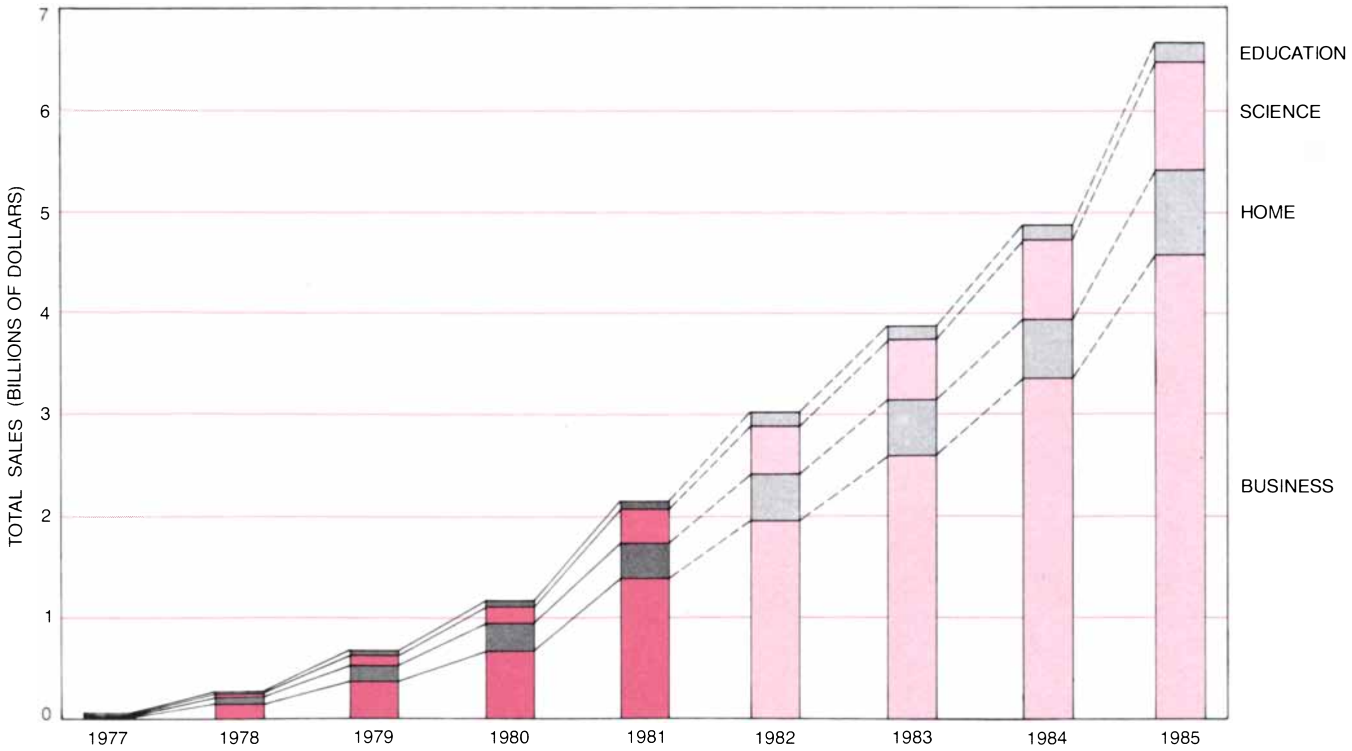
The part of the software that is most closely associated with the hardware is the operating system. To understand the kind of tasks done by the operating system, consider the sequence of steps that must be taken to transfer a file of data from the primary memory to disk storage. It is first necessary to make certain there is enough space available on the disk to hold the entire file. Other files might have to be deleted in order to assemble enough contiguous blank sectors. For the transfer itself sequential portions of the file must be called up from the primary memory and combined with "housekeeping" information to form a block of data that will exactly fill a sector. Each block must be assigned a sector address and transmitted to the disk. Numbers called checksums that allow errors in storage or transmission to be detected and sometimes corrected must be calculated. Finally, some record must be kept of where the file of information has been stored.

If all these tasks had to be done under the direct supervision of the user, the storage of information in a computer would not be worth the trouble. Actually the entire procedure can be handled by the operating system; the user merely issues a single command, such as "Save file." When the information in the file is needed again, an analogous command (perhaps "Load file") begins a sequence of events in which the operating system recovers the file from the disk and restores it to the primary memory.

In most instances an application program is written to be executed in conjunction with a particular operating system. On the other hand, there may be versions of an operating system for several different computers. Ideally, then, the same application program could be run on various computers, provided they all had the same operating system; in practice some modification is often necessary.

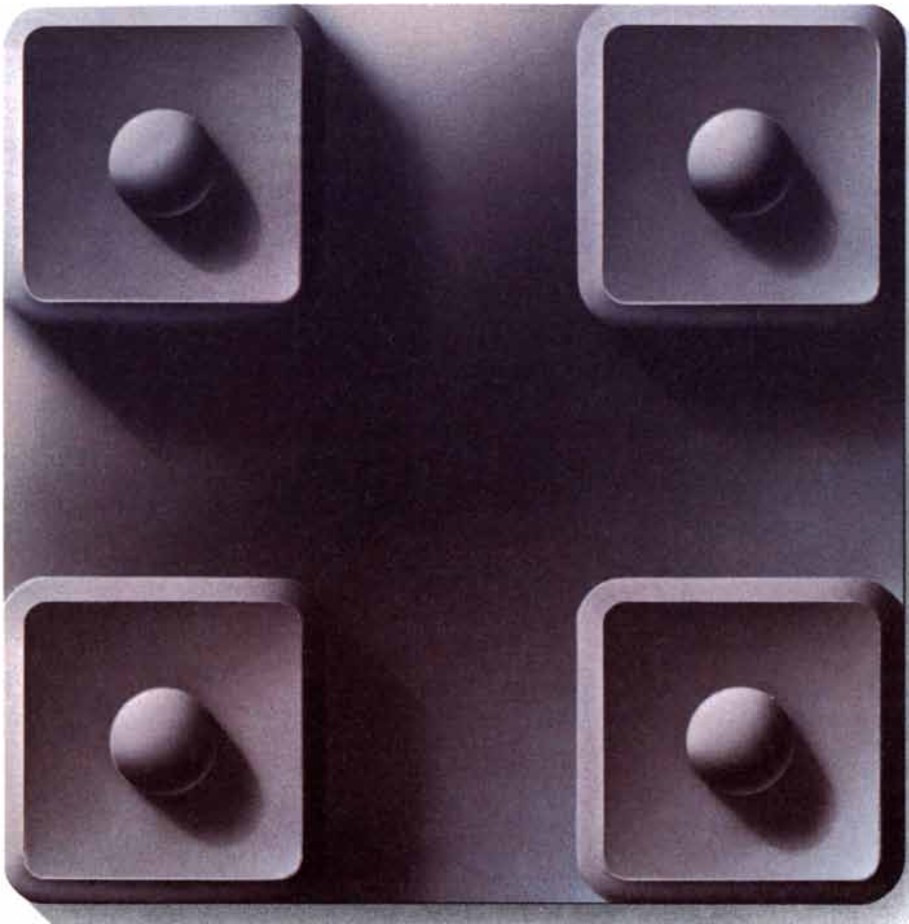
The microprocessor recognizes only a limited repertory of instructions, each of which must be presented as a pattern of binary digits. For example, one pattern might tell the processor to load a value from the primary memory into the internal register called an accumulator and another pattern might tell the machine to add two numbers already present in the accumulator. It is possible to write a program in this "machine language," but the process is tedious and likely to result in many errors.

The next-higher level of abstraction is an "assembly" language, in which sym-



PERSONAL-COMPUTER MARKET is expected to continue its exponential growth. The bars give the value of each year's sales of personal computers, as estimated and as projected by the authors, for the market's four segments: business, home, science and education.


JOHN JAMESON & SON
IRISH WHISKEY
ESTD 1780
SINE METU
JOHN JAMESON
IRISH WHISKEY
A BLEND
DISTILLED IN IRELAND BY
LIMITED
BOW STREET DISTILLERY
DUBLIN
IMPORTED



WHEN IN DOUBT, WAFFLE.

It's a complicated, confusing world out there.

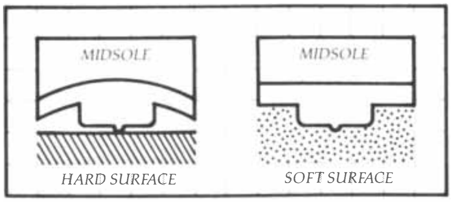
Just about the time you have it all figured out, everything turns to dust. Or gravel. Or sand. Or a two mile stretch of concrete. Followed by a rain-soaked field.

If you're a runner, there just aren't many simple answers in life. Save one.

The Waffle.

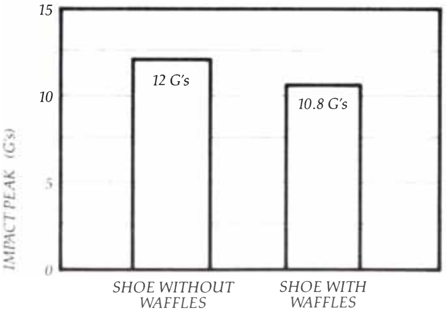
As familiar as this shape has become, nothing is better qualified to see you through the worst the world has to offer.

Because regardless of changes in terrain, each Waffle will continue to act as an independent shock absorber—penetrating softer surfaces, pushing into the midsole on harder ones.



Acting as an independent shock absorber, the Waffle tends to push into the midsole on harder surfaces while penetrating softer ones.

At our research lab in Exeter, New Hampshire, we found the addition of Waffles can increase the cushioning of a running shoe a full 10 percent.



The addition of Waffles to the same shoe significantly reduces impact shock.

Granted, it is possible to achieve somewhat the same thing by going to a flat outsole made of a much thicker, much softer rubber. Unfortunately, that means giving up both traction and wear.

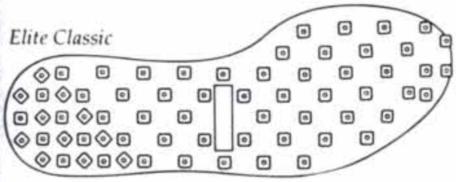
We also suspect the Waffle's square shape is superior to others during those critical changes in direction or stride. Compared to a circle, for example, the Waffle appears to require less torque to rotate, and should lessen both strain and fatigue.

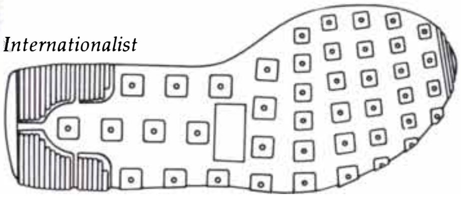
That's not to say we haven't tried to make improvements. We've come out with variations of that famous square ever since we introduced it, way back in 1972.

Via high speed film and computer analysis, we discovered that most runners tend to toe-out when they land. As a result, on some models, we have slightly altered the position of the Waffles.

But that's about it.

As far as discovering some revolutionary new shape or system better able to carry you through a changing world, we simply haven't. And neither has anyone else.





That's why for racing, we strongly recommend our new Elite Classic. And for training, the Internationalist.

The Waffle is featured on both. True, it isn't exactly new. But it also isn't equaled.

So the next time you're tempted to go with an outsole that looks more radical, remember.

Sometimes there's a definite advantage to being square.

NIKE

Beaverton, Oregon

bols and words that are more easily remembered replace the patterns of binary digits. The instruction to load the accumulator might be represented LOADA and the instruction to add the contents of the accumulator might be simply ADD. A program called an assembler recognizes each such mnemonic instruction and translates it into the corresponding binary pattern. In some assembly languages an entire sequence of instructions can be defined and called up by name. A program written in assembly language, however, must still specify individually each operation to be carried out by the processor; furthermore, the programmer may also have to keep track of where in the machine each instruction and each item of data is stored.

A high-level language relieves the programmer of having to adapt a procedure to the instruction set of the processor and to take into account the detailed configuration of the hardware. Two quantities to be added can simply be given names, such as *X* and *Y*. Instead of telling the processor where in primary memory to find the values to be added, the programmer specifies the operation itself, perhaps in the form $X + Y$. The program, having kept a record of the location of the two named variables, generates a sequence of instructions in machine language that causes the values to be loaded into the accumulator and added.

There are two broad classes of programs, called interpreters and compilers, that translate into machine code a program written in a higher language. A program written in an interpreted language is stored as a sequence of high-level commands. When the program is run, a second program (the interpreter itself) translates each command in turn into the appropriate sequence of machine-language instructions, which are executed immediately. With a compiler the entire translation is completed before execution begins. An interpreter has the advantage that the result of each operation can be seen individually. A compiled program, on the other hand, generally runs much faster since the translation into machine language has already been done.

Fortran was one of the earliest high-level languages and is now available in several versions (or dialects). Fortran programs are compiled; their main applications are in the sciences and mathematics. The most widely employed high-level language for personal computers is Basic, which was developed in the 1960's by workers at Dartmouth College. Basic was originally intended as an introductory language for students of computer programming, but it is now employed for applications of all kinds. Most versions of Basic are interpreted. There are dozens of other high-level languages that can be executed by a microcomputer. The choice of a language for a particular program is often based on the nature of the problem being addressed; the language called Lisp, for example, is favored by many investigators of artificial intelligence. Considerations of personal programming style also have an influence: the language Pascal has been gaining popularity in recent years because it is said to encourage the writing of programs whose underlying structure is clear and can be readily understood.

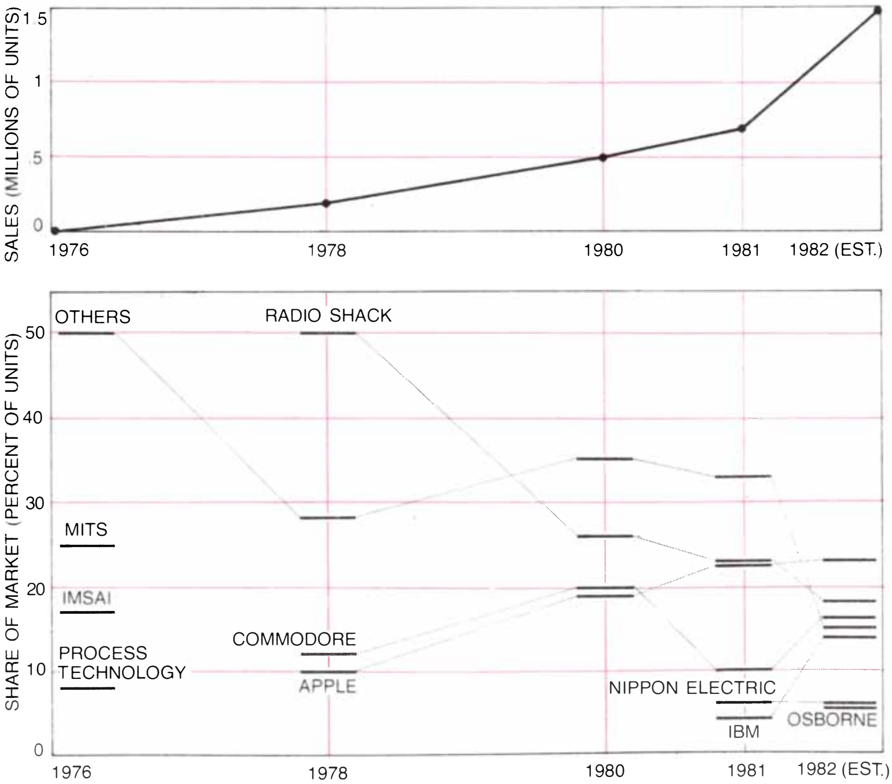
Application Programs

Application programs are the ones that ultimately determine how effective a computer is in meeting human needs. For this reason it is likely that the owner of a personal computer will eventually invest more in software than in hardware. The investment can be made either by buying programs or by spending the substantial amount of time needed to write them. Unless one wants to do intensive programming the breadth of a system's software base (the number of applications supported) and its depth (the number of different programs available for each application) should be significant considerations in the selection of hardware.

A thriving cottage industry supplying application programs has evolved. Many programs are highly specialized. There are programs, for example, for generating a Federal income-tax return or (in conjunction with the necessary instrumentation) for analyzing thousands of blood samples per hour or for designing a bridge. Other programs have more general applications. Word-processing software is a prime example: it facilitates the writing and editing of documents of any kind, from letters and memorandums to magazine articles such as this one.

The most popular single program for personal computers is called VisiCalc and is distributed by VisiCorp. It is an "electronic worksheet." The program lays out in the computer's memory and displays on its screen a table 63 columns wide and 254 rows deep. The user "scrolls" the worksheet right and left or up and down to bring different parts of it into view. Each position (that is, each intersection of a column and a row) on the screen corresponds to a record in memory. The user sets up his own matrix by assigning to each record either a label, an item of data or a formula; the corresponding position on the screen displays the assigned label, the entered datum or the result of applying the formula.

Consider a simple example. A company comptroller might enter the label *Cash* in the record corresponding to Column *B*, Row 1 (position *B*1), *Reserves* at *C*1 and *Total* at *D*1. He might then enter $300,000 at *B*2, $500,000 at *C*2 and the formula $+B2 + C2$ at position *D*2. The



ANNUAL SALES of personal computers have increased 100-fold in six years, more than doubling in the past year (*top*). The companies that pioneered in the industry failed to survive its first years. They were supplanted by companies whose products appeal to wider market (*bottom*).

screen will show \$800,000 at *D*2. If the comptroller changes the *B*2 entry to \$200,000, the program will reduce the total displayed at *D*2 to \$700,000. Moreover, what is entered in records *B*2 and *C*2 need not be primary data; it can be a function of data held in other records.

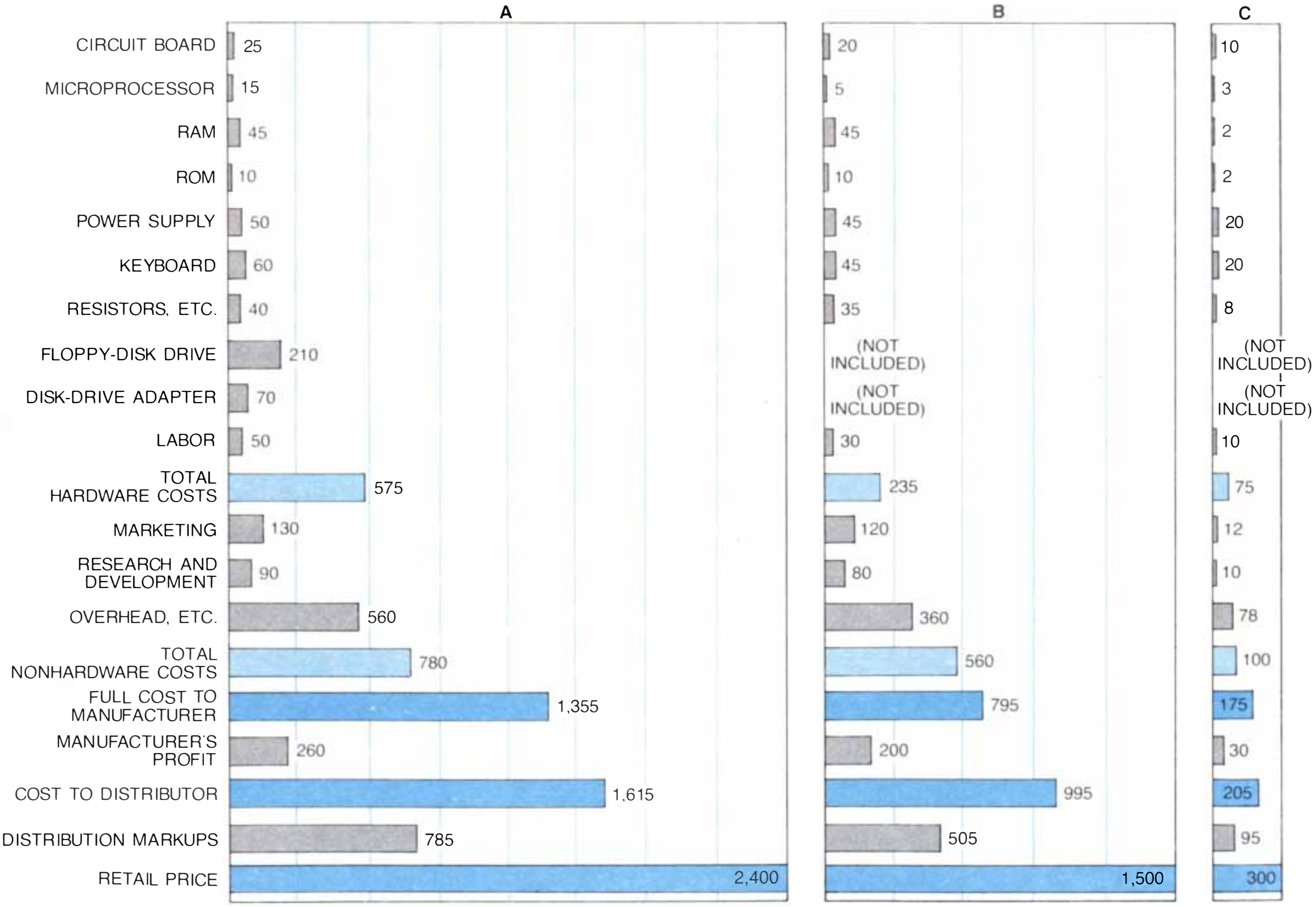
The Industry

The evolution of the small personal computer followed, perhaps inevitably, from the advent of the microprocessor. It was in 1971 that the Intel Corporation succeeded in inscribing all the elements of a central processing unit on a single integrated-circuit chip. That first microprocessor had only a four-bit word size, but within a year Intel produced an eight-bit processor and in 1974 there was an improved version, the Intel 8080. Small companies soon combined the 8080 with memory chips and other components to produce the first programmable microcomputers for industrial control and similar specialized applications. In 1975 a device flexible enough to be considered the first commercially available personal computer was developed by MITS, Inc. It was called the Altair 8800, and the basic system sold, primarily to hobbyists, for \$395 in kit form and for \$621 assembled. At the time the least expensive minicomputer cost about \$6,000.

The Altair is no longer made. As a matter of fact one irony of the personal-computer industry, whose annual sales have increased by a factor of 100 in just six years, is that pioneering firms such as MITS, the IMSAI Manufacturing Corporation and the Processor Technology Corporation failed to survive the initial phase. Their products were bought primarily by hobbyists: people with deep curiosity about computers and in most cases with some previous knowledge of electronics, who were willing—indeed eager—to grapple with the hardware. The companies that supplanted the pioneers and captured a major share of the market by 1978 were Radio Shack, Commodore Business Machines and Apple Computer Inc. They saw the potential of a wider market in business and in the home; they offered "plug in" systems that were more accessible to people without computer training. The success of the second-generation companies alerted established mainframe manufacturers such as the International Business Machines Corporation and the Burroughs Corporation and makers of minicomputers such as the Digital Equipment Corporation and the Hewlett-Packard Company to the fact that their traditional markets might be eroded by the personal computer; the established companies then came into the field. New companies continue to be attracted to the industry.

The personal-computer market can be divided into four segments: business, home, science and education. The business segment has already become by far the largest one. In 1981 it accounted for 385,000 unit sales (55 percent of total sales) with a retail value of \$1.4 billion (64 percent of the total value). There are 14 million businesses in the U.S., even the smallest of which is a potential buyer of a personal computer. Perhaps more important, there are some 36 million white-collar workers in the U.S., and a large fraction of them may eventually be working with a small computer of some kind.

The personal computer is currently best suited to the needs of small companies and of independent professionals such as lawyers and physicians. Larger organizations, however, are slowly coming to the concept of individual computer-centered work stations, which can be linked to one another and to central facilities (large memory units and



RETAIL PRICE of a personal computer reflects the cost to the manufacturer of the hardware components, labor and other nonhardware costs, the manufacturer's profit and the distributors' markups. Here these incremental costs have been estimated for three categories: a relatively high-cost, high-performance personal computer (*A*), a middle-level model (*B*) and an inexpensive, low-performance one (*C*).

3
For the first time a computer that "hears" has been used to design a music system.
Third in a series on how Delco Electronics and Bose technology contribute to your enjoyment of driving.
Traditionally the design of music systems has been based on measurements of sound waves produced by loudspeakers. These measurements tell us about the operation of the speakers and other components, but they say little about how people really perceive sound. Thus, traditional measurements are not very useful in designing better sounding music systems.
Now we have found a way around this fundamental problem. From research on the hearing process, we developed a computer that "hears." The computer receives signals from microphones in the ears of a mechanical head. It then processes these signals using knowledge of human hearing mechanisms.
With this computer we can evaluate and design music systems in a completely new way. Just one example: instead of a listener trying to describe where sounds appear to come from, the computer draws a "map" of sound localization. We can then adjust the placement and orientation of the four speakers so the sound is perceived as a panorama across the car. And, we do a unique design for each automobile model.
How much difference does our "hearing" computer make to your enjoyment? When you visit your GM dealer* and experience the Delco-GM/Bose Music System, you will know. Just try not to get excited!
*Available as a factory-installed option on Oldsmobile Toronado, Buick Riviera, and Cadillac Eldorado and Seville.
A totally new class of music systems from Delco-GM.
Delco GM BOSE
Sound so real, it will change how you feel about driving.

printers, for example) by local-area networks [see "The Mechanization of Office Work," by Vincent E. Giuliano; SCIENTIFIC AMERICAN, September]. Personal computers are already powerful enough to handle most work-station tasks, and networks are under development. By 1985 personal-computer networks will be in operation in many business organizations.

The home-computer segment, which is the most visible and well-publicized one, in 1981 accounted for 175,000 sales with a value of $350 million. Most of the units were bought for recreation (primarily for playing video games), but they also serve as powerful educational aids for children, as word processors, electronic message centers and personal-finance tools. A broad range of new applications will be made possible by software now under development. The average cost of a complete home system is expected to fall from about $2,000 now to perhaps $1,000 in 1985 and $750 in 1990.

The science segment accounted for 105,000 unit sales in 1981 with a value of $336 million. Computers intended for scientific and other technical applications tend to be more powerful than other personal computers and to have components that facilitate their being linked to analytical and sensing instruments. The market is therefore characterized by products with specialized hardware and an array of specialized programs.

The education segment is potentially very large, but it is critically dependent on the availability of funds; currently money is scarce for public-school systems. Nevertheless, in 1981 educational institutions bought 35,000 personal computers with a value of $98 million. Computer-assisted instruction involves the student in a lively interaction with subject matter in almost any field of study and allows the individual to proceed at his own pace. The ability to work with a computer is coming to be considered a necessary basic skill and even some programming ability may soon be required in many occupations; clearly the place to acquire such skills is in elementary and secondary school. Reasoning that a student trained with the computer of a particular manufacturer is likely someday to be a purchaser of that brand, Commodore has offered schools and colleges three machines for the price of two; Apple has proposed donating personal computers to U.S. primary and secondary schools.

Major Manufacturers

The industry leaders (in terms of estimated sales in 1982) are Apple, Radio Shack, Commodore and IBM. Although all of them are making a major effort to capture the largest share of the business market possible, they are trying to accommodate other segments as well.

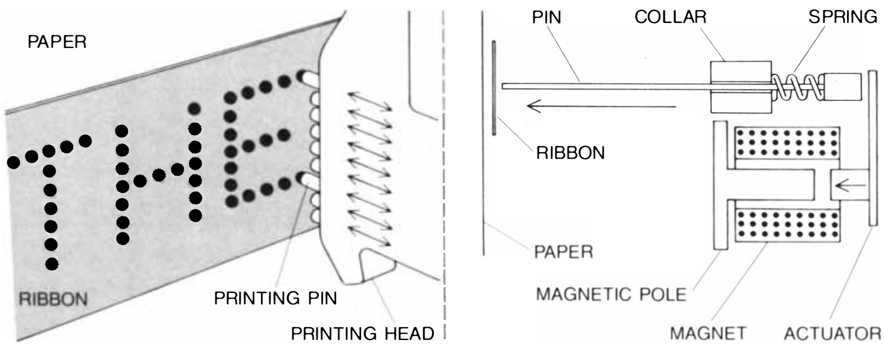
The company with the largest sales, not only in the U.S. but also worldwide, is Apple, whose first prototype was built in a garage in 1976. The company's first four years were financed by private investment and venture capital; it went public in 1980, but 64 percent of its stock is still held by insiders. Apple's sales in 1981 amounted to $335 million, 2.9 times as much as the year before, and its earnings were $39.4 million, 3.4 times as much as in 1980; it claimed 23 percent of the U.S. market, and U.S. sales accounted for only 76 percent of its total sales. Much of Apple's success is attributed to the company's policy of encouraging venders of software and peripheral equipment to develop and sell products that are compatible with Apple computers. For example, more than 11,000 application programs are available for Apple computers, 95 percent of them developed by independent venders. All three models of the Apple that are currently on sale are based on the same eight-bit microprocessor.

Radio Shack, which since 1963 has been owned by the Tandy Corporation, was a retailer and manufacturer of electronic products long before it went into computers, which today account for about a fifth of its volume. Although its sales have risen steadily, its share of the market has decreased from 50 percent in 1978 to an estimated 22 percent this year. Radio Shack has a broad line of computer products, including many that are manufactured internally, and exceptionally good distribution: in addition to its 8,000 full-line electronics stores there is a network of domestic and foreign computer centers that handle sales, leasing, service and training. The company's software is developed both internally and by other venders.

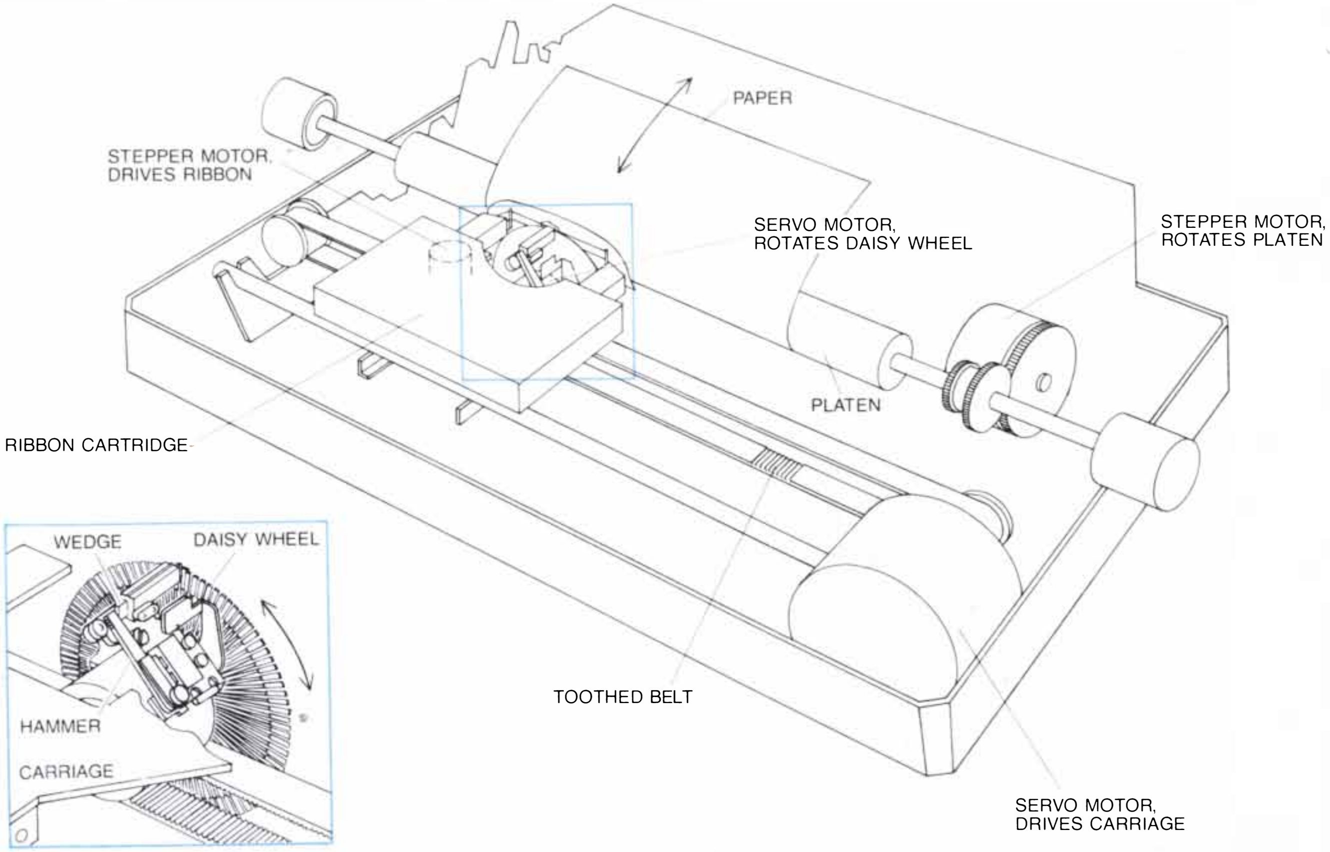
Commodore is a Canadian company that began in 1958 as a dealer in typewriters and in 1976 acquired MOS Technology, the original manufacturer of the microprocessor that is still used in Apple and Atari computers. Commodore has more sales outside the U.S. than any other company, and it has 65 percent of the European market. It has a broad line of inexpensive products (with one minimal model at $150) and has done well in the education segment.

IBM, the world's largest supplier of data-processing equipment, has long dominated the market for mainframe computers but had not done as well with smaller computers before entering the personal-computer field in mid-1981. It captured a substantial share of the market (an estimated 14 percent this year) with remarkable speed. The strategy was to rely heavily on outside sources not only for software, distribution and service but also for hardware: the IBM personal computer's disk drive is supplied by the Tandon Corporation, the monitor is from Taiwan and the printer is from Japan. The keyboard is supplied by IBM—and so is the brand name. IBM has established a publishing house that solicits new software programs from outside authors.

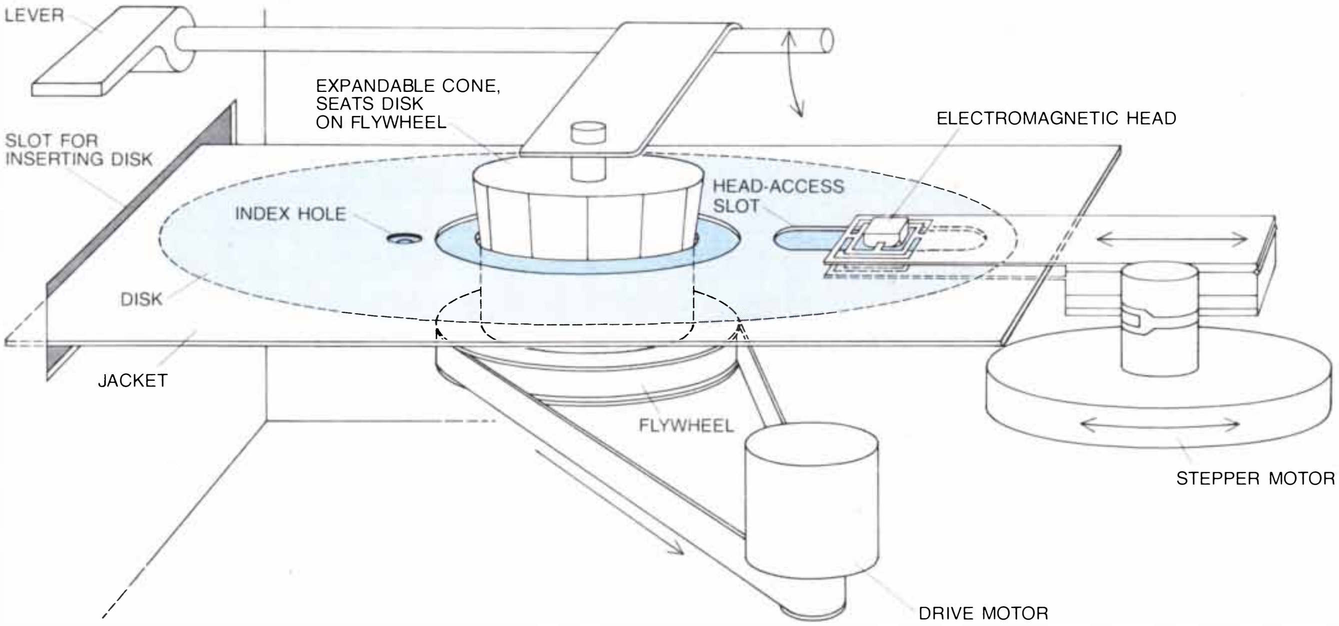
IBM's success has interesting implications for the future of the personal-computer business. The industry is volatile. American companies such as the Xerox Corporation and Atari, Inc., and a number of Japanese manufacturers (notably the Nippon Electric Co., Ltd.) are in a position to overtake the leaders. New entrants are in the wings. In evaluating their prospects one must consider what the requirements are for commercial success. What is clearly not mandatory, to judge from IBM's strategy, is established manufacturing capability. Rather, the fundamental requirements would seem to be the financial resources to buy the necessary components and the ability to market a product successfully and distribute it rapidly over a wide area.



DOT-MATRIX PRINTER is relatively inexpensive, fast (up to 200 characters per second) and flexible: it can generate compressed, expanded or bold characters or even graphic images, depending on the commands it receives from the computer. The printing head is a vertical array of pins that are fired selectively, as the head is swept across the paper, to press an inked ribbon against the paper and thereby form a pattern of dots (*left*). Here each capital letter is a subset of a matrix seven dots high and five dots wide; two more pins are available to form the descenders of lowercase letters such as *p*. The pins are fired by individual solenoids (*right*). The mechanism illustrated here is that of a dot-matrix printer made by Epson America, Inc.



DAISY-WHEEL PRINTER produces "letter quality" copy at a rate of from 20 to 55 characters per second. This is a schematic representation of a Qume Corporation printer. The printing wheel has a plastic hub around which are arrayed 96 (in some models 130) radial spokes; a letter, number or other symbol is molded into the end of each spoke. In response to signals from the computer the wheel is rotated either clockwise or counterclockwise to bring the proper symbol into position and is stopped; the hammer strikes (with an energy proportionate to the area of the symbol: much harder, say, for a *W* than for a comma), driving the sliding wedge against the end of the radial arm to press the inked ribbon against the paper; the carriage and ribbon advance as the wheel is spun to bring the next symbol into position.



FLOPPY-DISK SYSTEM records large quantities of information on a flexible plastic disk coated with a ferromagnetic material. The disk rotates at 300 revolutions per minute in a lubricated plastic jacket. An electromagnetic head is moved radially across the surface of the disk by a stepper motor to a position over one of the concentric tracks where data are stored as a series of reversals in the direction of magnetization. The head can read or write: sense the reversals to retrieve information or impose magnetization to store information. An index mark, whose passage is sensed by a photoelectric device, synchronizes the recording or reading with the rotation of the disk. This is a schematic drawing of a double-sided disk drive made by Qume. There are two gimballed heads, which read and write information on both sides of the $5\frac{1}{4}$-inch disk. On each side of the disk some 160 kilobytes of information can be stored in 40 concentric tracks.

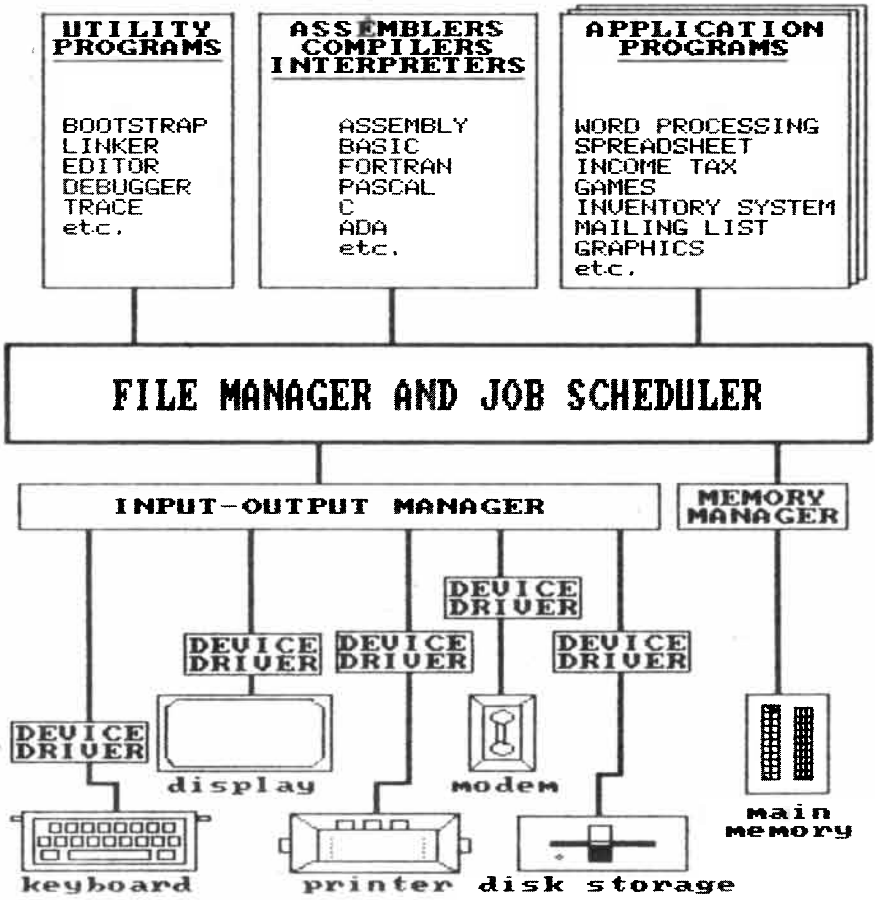
Many organizations, including some whose present business has nothing to do with electronics, have such capabilities and will be able to acquire technical expertise as it is needed. Organizations as disparate as CBS and Coca Cola, as Time-Life and the Prudential Insurance Co., have the resources and the access to marketing and distribution facilities that could enable them to enter the personal-computer market soon.

Distribution

Large computers are sold by the manufacturer's own sales staff, which deals directly with the individual or the organization planning to use the system. The profit margin on a personal computer is not large enough to warrant a direct-sales force of this kind. A number of other channels of distribution have therefore been developed, some by the manufacturers and some by retailing entrepreneurs.

Independent retailers who operate a single store have had a hard time with personal computers. They can order only limited quantities of a product and they tend to be too thinly capitalized to compete vigorously. They have been supplanted by franchised retail chains such as Computerland, which sold $200 million worth of computers and accessories in 1981. Such chains of stores offer the products of a number of manufacturers. They can afford a technical staff to advise the buyer and can provide long-term maintenance and servicing. Less specialized retail chains that deal in such electronic products as stereo components have added personal computers to their inventories. The lack of computer expertise in electronics stores has been a handicap. As the reliability of hardware improves and software becomes more standardized, however, and as Japanese companies (which have strong ties to the electronics chains) come into the market, such stores are likely to become a major channel of distribution.

Department stores have generally not had much success in selling personal computers. For one thing, they cannot provide sustained maintenance. Moreover, one study found that someone who buys a personal computer has made an



"BUSINESS GRAPHICS" SOFTWARE greatly increases the utility of personal computers and is responsible for much of their growing acceptance. This chart, a version of the illustration on page 92, was generated on a personal computer with Execu-Vision, a program distributed by Digital Systems Associates, and was printed out by a dot-matrix printer. The task took about 15 minutes. Rapid preparation of such charts, as well as graphs, tables and even drawings, with low-cost equipment is of major value in the preparation of reports and presentations.

average of four visits to a store, lasting for a total of seven hours; department stores are not accustomed to that kind of selling effort. Office-equipment stores, on the other hand, have contacts in their local business market and can provide the needed sales and service expertise. Sears has recently opened specialized stores in large cities to handle only personal computers, word processors and auxiliary equipment.

Manufacturers themselves sponsor a variety of outlets for their products. Radio Shack depends largely on its own chain of retail stores. IBM, Xerox and Digital Equipment are opening their own stores to supplement other channels of distribution. Texas Instruments maintains catalogue showrooms, where a customer can inspect the company's products, make a choice and leave an order that is filled from a central warehouse. Manufacturers may also find that a direct-sales staff is justified for bulk sales to government agencies, large corporations and academic institutions. Radio Shack and IBM have established such staffs. They run the risk of antagonizing retail dealers who might otherwise compete for these large sales.

Mail-order companies have been a significant presence in the personal-computer field. They handle large quantities and are able to offer large discounts but no on-site maintenance and servicing support. Moreover, full-service dealers are less likely to handle a product that is widely available at a discounted price.

A new kind of outlet that is peculiar to the personal-computer field is the "value-added house." It buys hardware from the manufacturer, buys or develops peripheral equipment and software for a specific application or a specific kind of user and offers a complete package. The services of a value-added house can be particularly attractive to an organization with little computer expertise.

Who Needs It?

In spite of the implications of the word "personal" and the popular image of family members gathered around the home computer to do schoolwork, balance the checkbook and shoot down spacecraft, it is clear that most personal computers are being bought by businesses and other organizations. That does not necessarily make the computer any less personal; it may still be dedicated to the needs of one individual. More than a fifth of the U.S. labor force is engaged in office work; office costs constitute more than half of the total costs incurred by many companies, and those costs are increasing at a rate exceeding 7 percent per year. Personal computers can increase the productivity of the office and of white-collar workers. In an organization that already has a mainframe computer personal computers can lighten the load on the central facility, which can spend more time on "batch" data-processing tasks such as payroll or inventory control. Personal computers make possible the mechanization of a wide range of office tasks that have been handled with typewriters, calculators and photocopying devices.

Managers in business are said to devote more than 80 percent of their time to preparing for and attending meetings and "presentations," to collecting information or to making decisions based on analysis of alternatives. Personal computers have impact on all three activities. New "business graphics" programs make it possible to quickly generate slides and printed material for meetings. Winchester disks and programs for the storing and management of large data bases help the individual to examine a large body of information, discern trends and detect problems. Data-manipulation programs such as VisiCalc enable the manager to evaluate alternative courses of action, to ask the kind of question that begins "What if" and to get an answer almost instantaneously. Such tasks can in principle be accomplished with a centralized mainframe computer, but they are done more efficiently with a personal computer, with far less expenditure of capital and by individuals who have had no technical training.

All of this having been said, the fact remains that the exact role to be filled by personal computers in an organization often cannot be foreseen. Many organizations have found that rather than meeting a known need, the presence of a personal computer identifies a previously unidentified need (much as the availability of a physician may bring to light a previously unrecognized health problem) and then meets that need.

Whether an individual needs or will profit from or enjoy his own personal computer is harder to say. For some professionals, to be sure, the advantage of having a computer always ready to hand is quite clear. Other people may buy one essentially because it is available and affordable, with the applications to be defined later. Specific applications will flow from the capabilities of the computer. A computer keeps track of things and sorts things. It calculates. It can marshal a large body of data, change one variable or more and see what happens. It can indeed balance a checkbook (rather, the owner can balance his checkbook with the help of the computer), list appointments or be linked to a home-security system. None of these applications by itself would justify the purchase of a computer. With curiosity and ingenuity, however, the owner of a personal computer will define his own applications, shaping the system to his own personality and taste.

Samples of the Milky Way

Cosmic rays are nuclei from other regions of our galaxy. Satellite observations of such nuclei indicate that the isotopic composition of those regions differs from the composition of the solar system

by Richard A. Mewaldt, Edward C. Stone and Mark E. Wiedenbeck

Advances in space technology and instrumentation now make it possible to determine the composition of samples of matter from elsewhere in our galaxy, the Milky Way. Although the direct sampling of matter from outside the solar system is out of the question, one can accomplish the same thing by intercepting authentic "starry messengers": cosmic rays, which are high-energy fragments of matter from other stars. Analyses of cosmic rays over the past four years by instruments aboard a specialized satellite observatory reveal that the composition of cosmic-ray material from our galaxy is distinctly different from the composition of the sun and the other bodies of the solar system. It is likely that such differences in composition result from differences in the conditions under which elements are synthesized deep inside stars.

Approximately 90 percent of the matter in our galaxy is hydrogen. The rest is mainly helium; about 1 percent is heavier elements. It is primarily the thermonuclear conversion of hydrogen into helium and helium into heavier elements, with a resulting release of energy, that causes the stars to shine. The composition of a galaxy evolves with time as some of the atomic nuclei synthesized inside massive stars are ejected by supernova explosions into the interstellar gas, which therefore gradually accumulates atoms from many stars. The solar system represents a sample of the atomic mixture that condensed some five billion years ago from the interstellar gas in one tiny region of our galaxy. The mixture may well have not been typical of the galaxy as a whole.

Some of the nuclei ejected by supernovas may be accelerated during the explosion to nearly the velocity of light and become cosmic rays. Still other nuclei in the interstellar gas may be accelerated to high velocities by the shock waves from later supernovas. Because atomic nuclei are electrically charged, they interact with the magnetic field of the galaxy; they are confined by the magnetic field for periods on the order of 10 million years before they finally escape into intergalactic space. Before the cosmic rays leave the galaxy some of them pass close to the earth, where they can be captured and analyzed. The capture and analysis must be accomplished in space, however, because cosmic-ray nuclei that enter the earth's atmosphere are shattered by collisions with the nuclei of the atoms of the atmosphere before they can reach the earth's surface.

Early investigations conducted with instruments carried by high-altitude balloons and on spacecraft established that about 1 percent of the cosmic rays are the nuclei of elements heavier than hydrogen and helium. These investigations also showed that the common heavier elements (such as carbon, oxygen, magnesium, silicon and iron) in cosmic rays are present in about the same relative abundances as they are in the solar system. By improving the precision of cosmic-ray measurements, however, one can look not only for the abundances of atomic nuclei but also for the abundances of isotopes: species of atomic nuclei.

The isotopes of the elements are distinguished by their mass. Elements differ from one another by the number of protons in their nuclei (designated Z), ranging from the single proton of hydrogen to the 92 protons of uranium. Isotopes of an element differ from one another by the number of neutrons in their nuclei: none in ordinary hydrogen (H-1), one in heavy hydrogen, or deuterium (H-2), on up to 143 and 146 neutrons in the two most abundant isotopes of uranium, U-235 and U-238. Since protons and neutrons are nearly equal in mass, the isotopes of an element differ from one another by integral numbers of mass units. By measuring the isotope abundances in cosmic-ray nuclei one can hope not only to detect material that may have a composition different from that of the solar system, and therefore a different history, but also to learn about the different element-building processes that take place inside stars of different types.

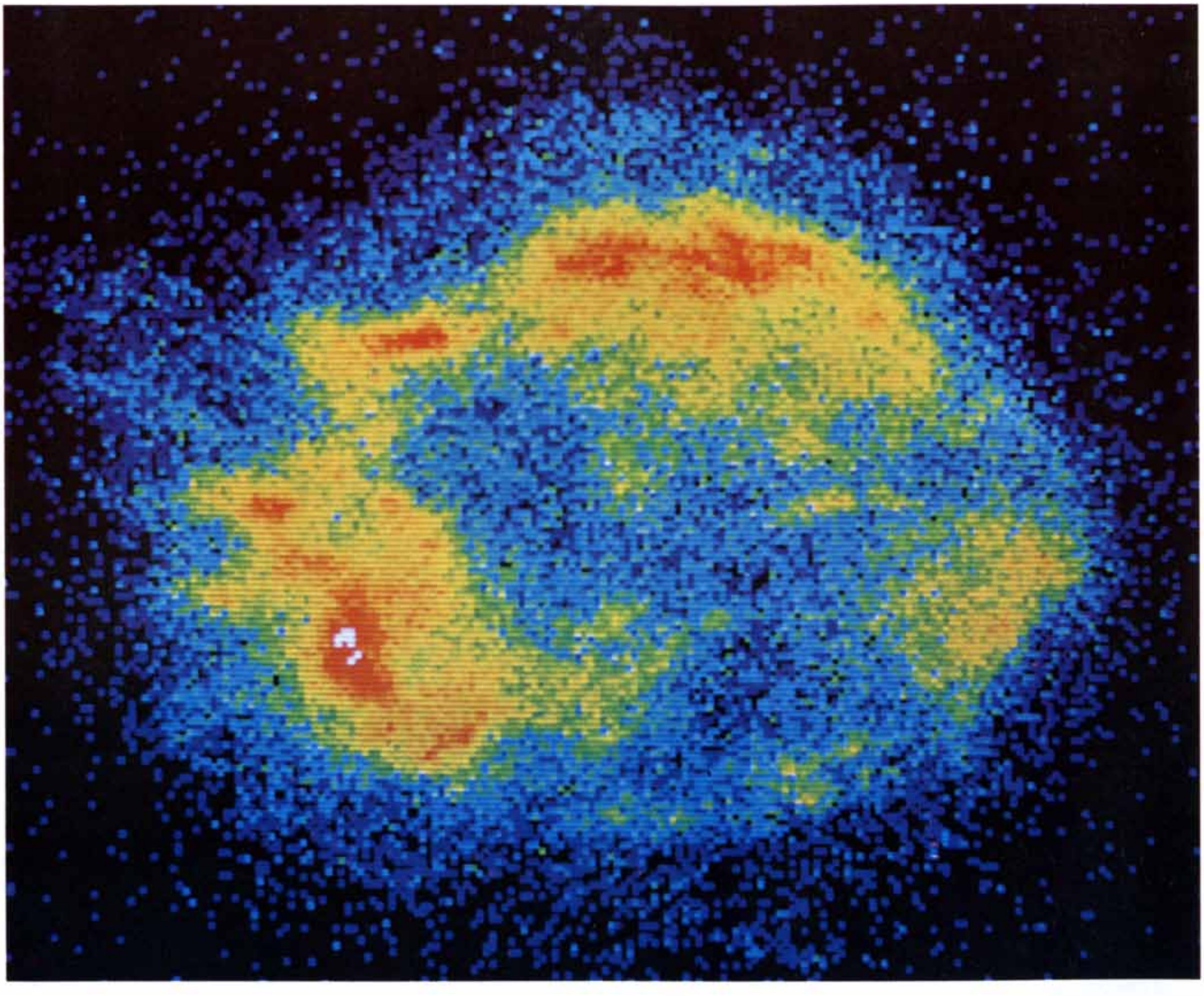
Measuring the mass of isotopes is readily accomplished in the laboratory with a mass spectrometer, an instrument nearly the size and weight of a baby-grand piano. To perform the same measurement in space with an instrument weighing less than 10 kilograms and consuming less than 10 watts of power is more difficult. Moreover, the space instrument must work with individual high-energy nuclei rather than a bulk sample of material. In addition it must be capable of returning measurements of high precision while operating unattended for a period of years. Two such instruments were built, one at the University of California at Berkeley and one at the California Institute of Technology. They were borne aloft in August, 1978, by the National Aeronautics and Space Administration's Third International Sun-Earth Explorer (ISEE-3), the first satellite to carry instruments specifically designed to measure the isotopic composition of heavy cosmic-ray nuclei. The space vehicle also carries 10 other experiments for measuring a variety of other interplanetary and astrophysical phenomena.

ISEE-3 was placed in an unusual "halo" orbit some 1.5 million kilometers from the earth (a hundredth of the distance to the sun) near a "Lagrangian point" where it is subject to comparable gravitational pulls from the earth and the sun. With the aid of small thrusts of gas ISEE-3 follows a gently sinusoidal path that carries it slightly above and then below the plane of the earth's orbit. When it crosses the orbital plane, it is alternately slightly ahead of or slightly behind a line between the earth and the sun. Thus as viewed from the earth ISEE-3 appears to be executing a halo around the sun, offset from it by an angle of about 15 degrees.

The purpose of the two spectrometers in the space vehicle is to determine the mass distribution of cosmic-ray nuclei by "weighing" them one at a time to an accuracy of better than 1 percent. The principle of operation of both instruments involves measuring the kinetic energy, *E,* and the velocity, *v,* of an incoming nucleus and deriving the mass, *m,* from the equation for kinetic energy: $E = \frac{1}{2}mv^2$. Thus *m* equals $2E/v^2$, where mass is expressed in units of nucleon mass, that is, the mass of a proton or a neutron. Nuclei traveling with velocities of 25 to 75 percent of the speed of light are monitored. For the nuclear mass to be determined with a precision of 1 percent the velocity of the nuclei must be measured with an accuracy of a few tenths of a percent.

The basic sensing elements of both instruments are solid-state detectors: thin wafers of silicon with an area of about 10 square centimeters. When an energetic nucleus passes through such a wafer, the positive electric charge on the nucleus frees some of the electrons from the crystal lattice of the silicon. As the nucleus loses kinetic energy to the electrons it is slowed down. By applying a voltage between electrodes deposited on the faces of the detector it is possible to collect the freed electrons, thereby generating a small electrical signal proportional to the kinetic energy lost by the nucleus. The more protons there are in the nucleus, the greater the positive charge is and the more energy it will lose to the electrons. On the other hand, the higher the velocity of the nucleus is the less energy it will lose because it spends less time passing through the silicon wafer. The overall loss of energy by the nucleus in passing through a detector is roughly proportional to Z^2/v^2, the square of the charge divided by the square of the velocity. As the nucleus passes through successive detectors it continues to slow down and lose energy until it stops. The sum of the electrical signals from the stack of detectors is a measure of the kinetic energy originally carried by the nucleus.

In principle *Z, m* and *E* can be determined uniquely for individual cosmic-ray nuclei that come to rest in the spectrometer. The energy lost in the spectrometer also depends, however, on the length of the path of the nucleus in the instrument, which of course varies for



SUPERNOVA REMNANT in the constellation Cassiopeia, Cas A, is an example of a region of our galaxy where nuclear particles are accelerated to high velocities to become cosmic rays. In this color-coded X-ray image (obtained with a detector on the satellite named the Einstein Observatory) the bright ring of intense X-ray emission (*red and yellow*) is formed by an expanding shell of stellar material ejected by the supernova explosion mixed with interstellar gas. A larger shell of material (*blue*) is presumably interstellar gas heated by the outward-traveling shock front of the explosion. Such shock waves are thought to accelerate cosmic rays. On the basis of Cas A's estimated distance of 9,000 light-years the bright ring has a diameter of about nine light-years. From the size and expansion velocity of the ring it is estimated that the explosion took place some 325 years ago, but there is no record of its having been observed on the earth. It is the youngest supernova remnant known in our galaxy. In supernova explosions the heavy elements formed in massive stars are dispersed into the interstellar gas, changing the composition of the galaxy over a period of time. X-ray image was obtained by Stephen S. Murray and his colleagues at the Center for Astrophysics of the Harvard College Observatory and the Smithsonian Astrophysical Observatory.


OLYMPUS
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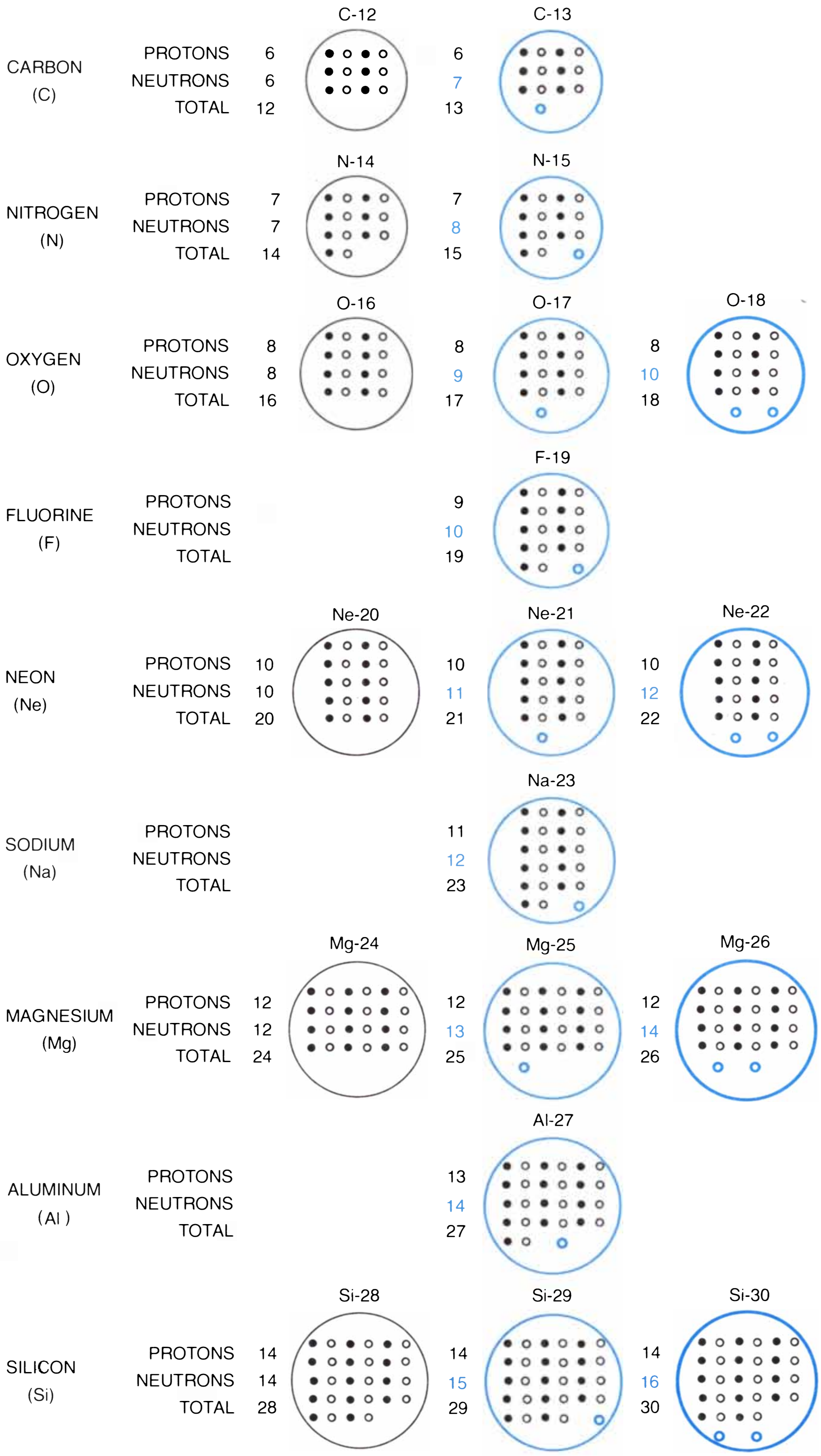
nuclei arriving from different directions. Cosmic-ray nuclei arrive uniformly from all directions. If one wants to measure the mass of a nucleus with an accuracy of better than 1 percent, one must determine its path length with a precision better than that. The feature that enables the Berkeley and Cal Tech instruments to identify isotopes of elements where earlier instruments of similar design could identify only elements is the addition of position-sensitive detectors at the entrance of the spectrometer. In the Cal Tech instrument trajectories are determined by a combination of two position-sensitive solid-state detectors; the Berkeley instrument relies on six gas-filled "drift" chambers for the same purpose.

Since ISEE-3 circles the sun rather than the earth and remains outside the earth's magnetic field, it can continuously observe energetic cosmic rays from the galaxy. When a cosmic ray stops in one of the spectrometers, the instrument records the signals from the various detectors for transmission back to the earth. The spectrometers respond to a wide range of elements from hydrogen to nickel, which has 28 protons. Our colleagues in these experiments include Douglas E. Greiner and Harry H. Heckman of the Lawrence Berkeley Laboratory and John D. Spalding and Rochus E. Vogt of Cal Tech. In what follows we shall concentrate on our measurements of the isotopes of neon, magnesium and silicon because of their special significance for studying nucleosynthesis in stars.

Neon, magnesium and silicon, respectively with 10, 12 and 14 protons, have three stable isotopes each. In solar-system material the dominant isotopes are neon 20, magnesium 24 and silicon 28, nuclei made up of equal numbers of neutrons and protons. They can therefore be regarded as being composed respectively of five, six and seven alpha particles: helium nuclei (He-4) consisting of two protons and two neutrons. Such "alpha-particle nuclei" are particularly stable and are copiously manufactured in normal stellar processes.

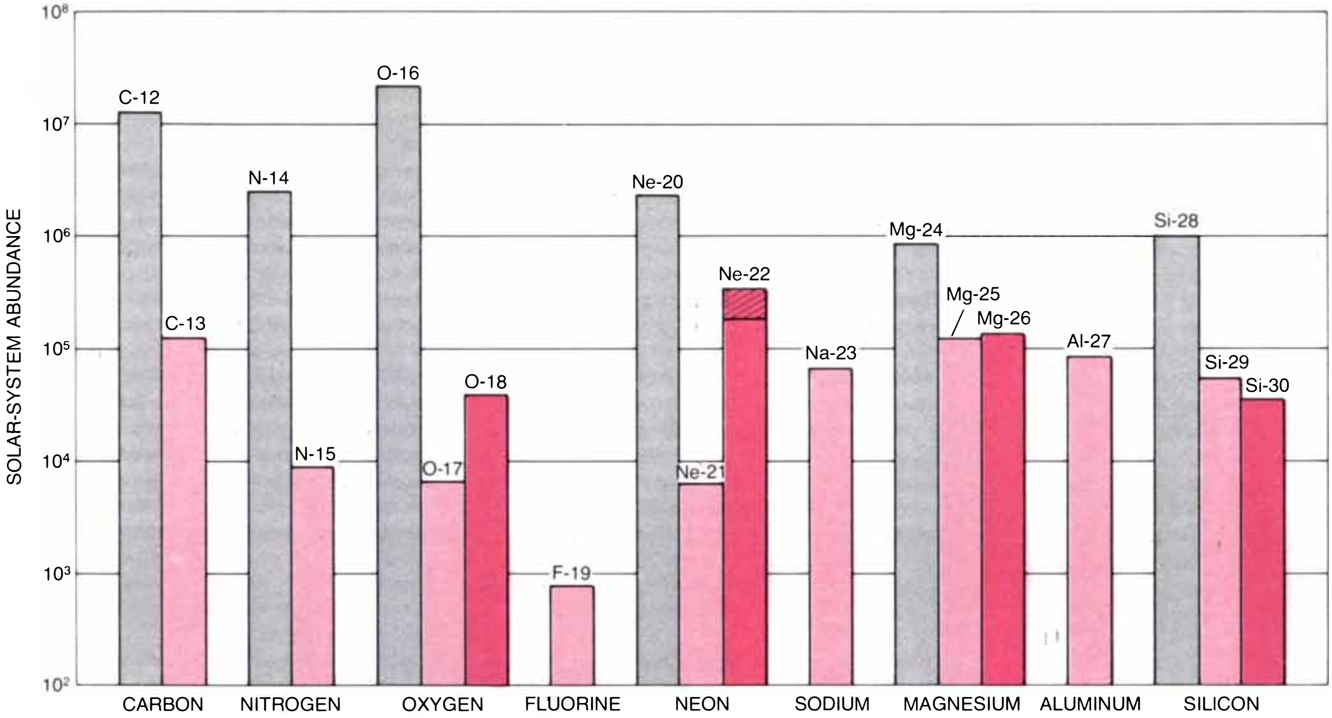
In the mid-1970's experiments by workers from the University of New Hampshire, the Goddard Space Flight Center of NASA and the University of Chicago demonstrated that the neon, magnesium and silicon in cosmic rays resemble solar-system material in being dominated by the same alpha-particle isotopes. Although this finding was not unexpected, it was important in demonstrating that the majority of cosmic rays do not arise from abnormal processes of nucleosynthesis. In order to extract more quantitative information on whether the nucleosynthesis of cosmic-ray and solar-system matter has differed, however, it is necessary to mea-



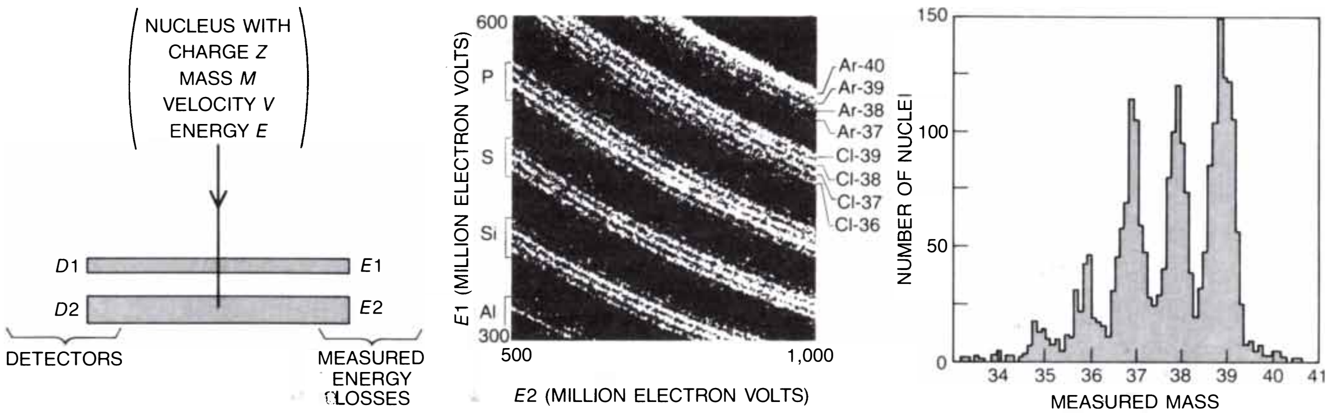
ALL NATURALLY OCCURRING ISOTOPES, or nuclear species, of the nine elements from carbon through silicon are depicted schematically. Three of the elements (fluorine, sodium and aluminum) have only one such stable isotope. The six isotopes in the first column, which have equal numbers of protons (*black*) and neutrons (*open circles*), are those most readily synthesized in stars and are therefore the most abundant members of their species. Isotopes in the second column have one extra neutron (*colored circle*) and those in the third column have two extra neutrons. Because they are more difficult to synthesize the isotopes with extra neutrons are less abundant. All the nuclei in the first column except for nitrogen 14 (N-14) are often called alpha-particle nuclei because they can be regarded as made up of alpha particles (nuclei of helium 4, consisting of two protons and two neutrons). Nuclei have a positive charge *Z*, equal to the number of protons. Protons and neutrons are collectively called nucleons.

sure the relative abundances of the heavier and rarer isotopes of neon, magnesium and silicon, those that contain either one extra neutron or two.

The spectrometers aboard ISEE-3 were the first to yield well-resolved measurements of these rarer neutron-rich isotopes. In analyzing the results one must first correct for the fact that some of the observed nuclei are secondaries, or fragments, resulting from the breakup of heavier cosmic-ray nuclei that have collided with atoms of interstellar gas. The percentage of secondaries in the total sample can be estimated by observing the abundances of certain nuclei that are relatively rare among the products of nucleosynthesis and therefore should be essentially absent unless they were formed by fragmentation. Such nuclei include those of lithium, beryl-



RELATIVE ABUNDANCES IN THE SOLAR SYSTEM of elements from carbon through silicon reflect the distribution of elements in the interstellar gas from which the sun, the planets and the other bodies in the solar system condensed five billion years ago. The isotopes are plotted on a logarithmic scale in which the abundance of silicon 28 (Si-28) is taken to be 10^6. The abundances are based primarily on measurements of the composition of solid bodies in the solar system rather than of the composition of the sun. The compilation was made by A. G. W. Cameron of Harvard University. The values serve as a standard against which the distribution of isotopes in cosmic rays can be measured. Any differences between solar-system matter and cosmic-ray matter that show up can be attributed to differences in the stellar conditions under which the two populations of matter were synthesized. The solar-system abundance of neon 22 is uncertain (*hatched area*) because both meteorites and particles emitted from the sun exhibit several distinct isotopic compositions.



MASS SPECTROMETER designed for cosmic-ray analysis identifies elements and isotopes by measuring the energy individual nuclei lose as they are slowed down and stopped by two solid-state detectors (*left*). The instrument yields electrical signals proportional to the energy lost in each of the two detectors. In essence the spectrometer identifies elements because their energy loss is approximately proportional to Z^2/v^2: the square of the electric charge divided by the square of the velocity. Isotopes of the same element are separated because their kinetic energy ($E = \frac{1}{2}mv^2$) is proportional to the mass. The photograph in the middle depicts the isotope separation achieved with the spectrometer built at the California Institute of Technology during a calibration run at the Lawrence Berkeley Laboratory. The source was a beam of argon 40 (Ar-40) supplied by the Bevalac accelerator. Many of the argon-40 nuclei fragmented into lighter nuclei on striking a target. The assortment of nuclei penetrated a detector .5 millimeter thick and were stopped in a second detector 1.7 millimeters thick. Each of more than 10,000 nuclei from aluminum ($Z = 13$) to argon ($Z = 18$) appears as a point in one of the six broad bands. The narrow tracks within each band correspond to separate isotopes of each element. The measurements must be approximately 10 times more precise to identify isotopes than they must be to identify elements. Resolution of five isotopes of chlorine is plotted at the right.

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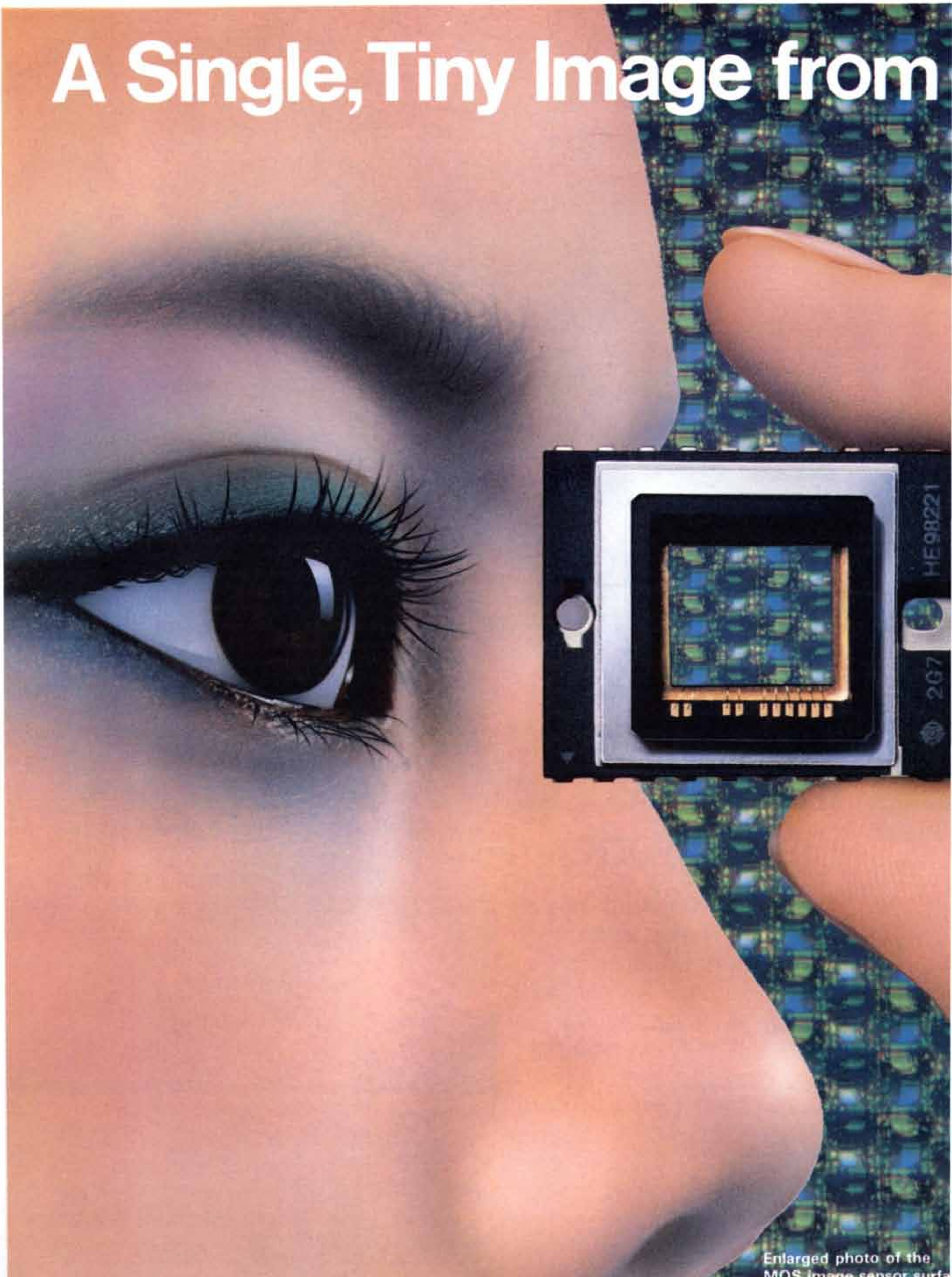
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2G7
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MOS image sensor surfa

180,000 Electrical Signals

To shrink the TV camera, start with the pickup tube

Beginning with the transistor in the early 1950s, solid-state components have been instrumental in producing compact electrical equipment by replacing bulky vacuum tubes. But unlike radios and televisions, TV cameras have been largely unaffected by this trend. Built into each conventional camera is a pickup tube that acts like an artificial retina to read images coming in through the camera lens. The intricate mechanism within its glass-enclosed vacuum allows the tube to convert these images into signals indicating shape, light intensity and color. Yet even Hitachi's own SATICON® pickup tube—the smallest of its type in the world—is almost 10 cm long. So the first step toward creating truly miniature TV and video cameras is to shrink the size of this vital component.

Hitachi's solid-state solution

Hitachi's approach to this problem was to replace the pickup tube with totally solid-state circuitry. The result of our research: a metal-oxide semiconductor (MOS) image sensor. This single-chip sensor consists of more than 180,000 photodiodes arranged in a 485×384 matrix on a rectangular silicon substrate. In area, the diode array is just one tenth as large as a postage stamp. When light from an image strikes these photodiodes, electric current is generated and picked up line by line at high speed through MOS transistor switches, thus producing video signals. Although this principle has been known for some time, no one had ever been able to put it into practical use. It required the highly precise, micrometric fabrication techniques and new advances in resolution power and color separation that only Hitachi engineers could provide.

Every one of the 180,000 diodes is equipped with a filter

One of the basic challenges was to fit the diodes with mosaic color filters capable of rendering color information as electrical signals. These filters had to be directly mounted piece by piece on each one of the 180,000 photodiodes, a mere 20μm in size. Difficult as this task is to imagine, much less carry out, the patience and ingenuity of Hitachi researchers made it all possible. And the MOS image sensor is just the first revolutionary step in creating an entirely new generation of miniature TV cameras. Soon there will be home video cameras no bigger than cigarette packs and studio cameras small enough for one-hand operation. What's more, Hitachi engineers are even envisaging capsulated medical cameras so tiny that they can be used for internal diagnosis. The potential benefits of such micro-cameras are virtually limitless.

Technical excellence is embodied in all Hitachi products

The development of MOS image sensors is just one case demonstrating Hitachi's technological strength. You'll find other examples in all of Hitachi's products, from TVs and VTRs to a whole host of high-quality electronic appliances. Our comprehensive technical expertise is your guarantee of convenience, easy operation and high reliability in every product that bears the Hitachi brand.

MOS Color Video Camera VK-C2000

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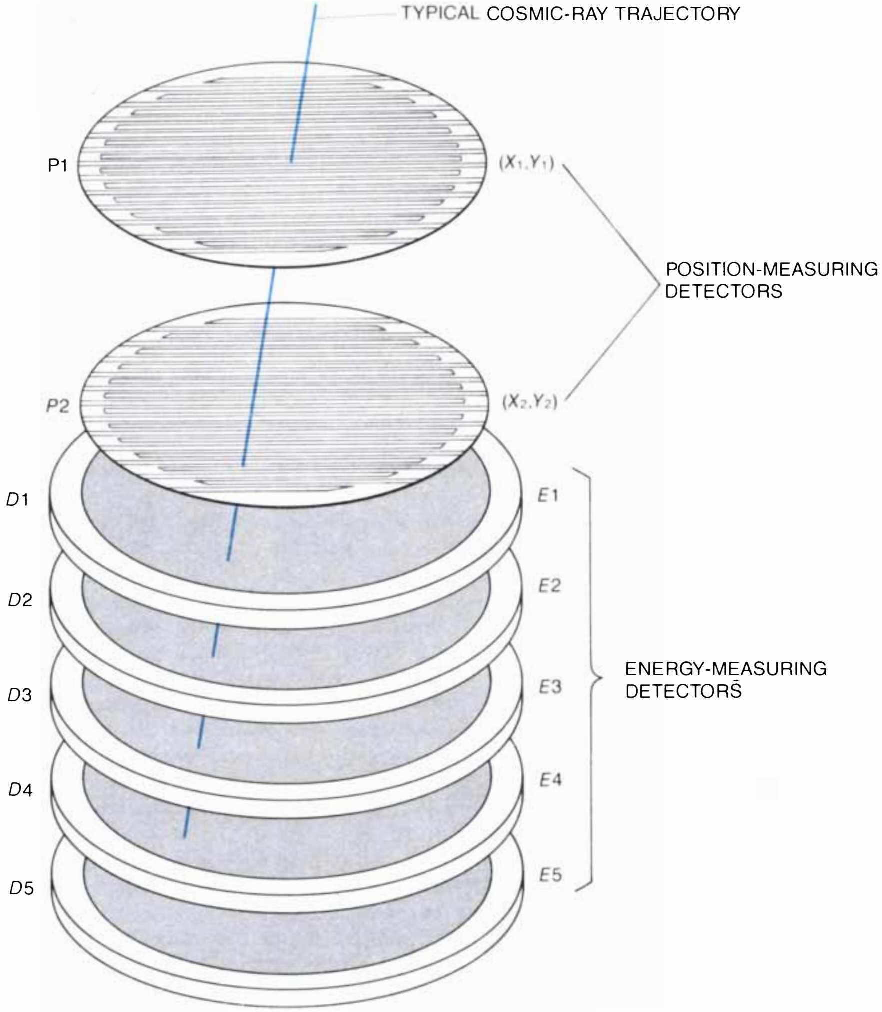
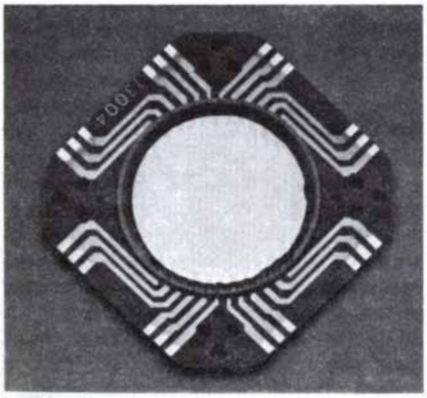
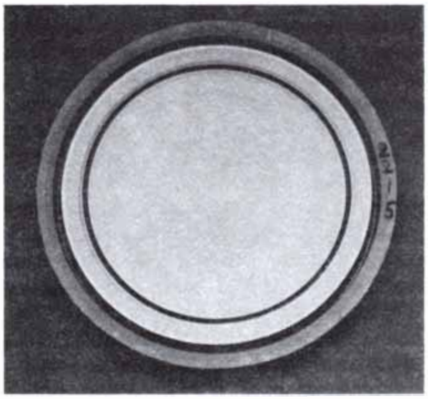


DETERMINATION OF COSMIC-RAY TRAJECTORIES is essential to the operation of an isotope spectrometer in space, where cosmic rays arrive from all directions. The energy the incoming nucleus loses in passing through the stack of detectors depends on the particle's path length through the instrument. Information supplied when a nucleus passes through two position-sensitive detectors (P_1, P_2) makes it possible to compute trajectory and hence path length.





POSITION-SENSITIVE DETECTOR in the photograph at the left has 24 parallel metallic strips on one surface of the circular wafer of silicon and, perpendicular to them, another set of 24 strips on the other surface. The detector thus provides one set of *x-y* coordinates for an incoming cosmic ray. By means of two such detectors, one above the other, the Cal Tech spectrometer determines the trajectories of incoming nuclei. The photograph at the right shows one of the 10 energy-measuring detectors that are stacked below the position-sensing detectors. This detector has two detection areas (*lighter gray*). The ring surrounding the central disk serves to detect nuclei that enter or leave through the side of the instrument. The Cal Tech spectrometer is one of the two carried into space by the Third International Sun-Earth Explorer (ISEE-3). The second instrument, built at the University of California at Berkeley, incorporates similar energy-measuring detectors but a different scheme for determining trajectories.

lium and boron (respectively with three, four and five protons) and isotopes such as oxygen 17 and neon 21. With the exception of neon 21 it appears that three-fourths of the neutron-rich isotopes of neon, magnesium and silicon are virgin, or primary, nuclei from the cosmic-ray source that have survived their 10-million-year journey through interstellar space intact; only about a fourth are secondaries created in collisions.

After making this correction we find that the isotope abundances in cosmic rays differ significantly from those in solar-system material. The most dramatic difference is the prevalence of neon 22 in cosmic rays. In solar-system samples there are only between seven and 12 nuclei of neon 22 for every 100 nuclei of neon 20. In the cosmic-ray source we find nearly 50 nuclei of neon 22 for every 100 of neon 20. In addition the four neutron-rich isotopes of magnesium and silicon (Mg-25, Mg-26, Si-29 and Si-30) are about 60 percent more plentiful in the cosmic-ray source than they are in solar-system samples. Although the excess of neon 22 in cosmic rays had been reported previously by the New Hampshire, Goddard and Chicago workers, these earlier experiments had not been sensitive enough to detect the smaller enhancements in the neutron-rich isotopes of magnesium and silicon.

The size of the cosmic-ray anomalies, ranging from 60 percent to several hundred percent, is impressive when one considers that the isotope anomalies reported in recent years for some meteorites are usually on the order of 1 percent or less in the abundance ratio of two isotopes, for example magnesium 25 and magnesium 24. In other solar-system samples one exception to near-uniformity is in the ratio of neon 22 to neon 20, which varies by nearly a factor of two. The most reasonable interpretation for the large cosmic-ray anomalies is that many of the nuclei that end up as cosmic rays were synthesized under conditions different from those that created typical solar-system nuclei. In order to understand how such differences might arise, we need to consider some of the processes operating in stellar nucleosynthesis.

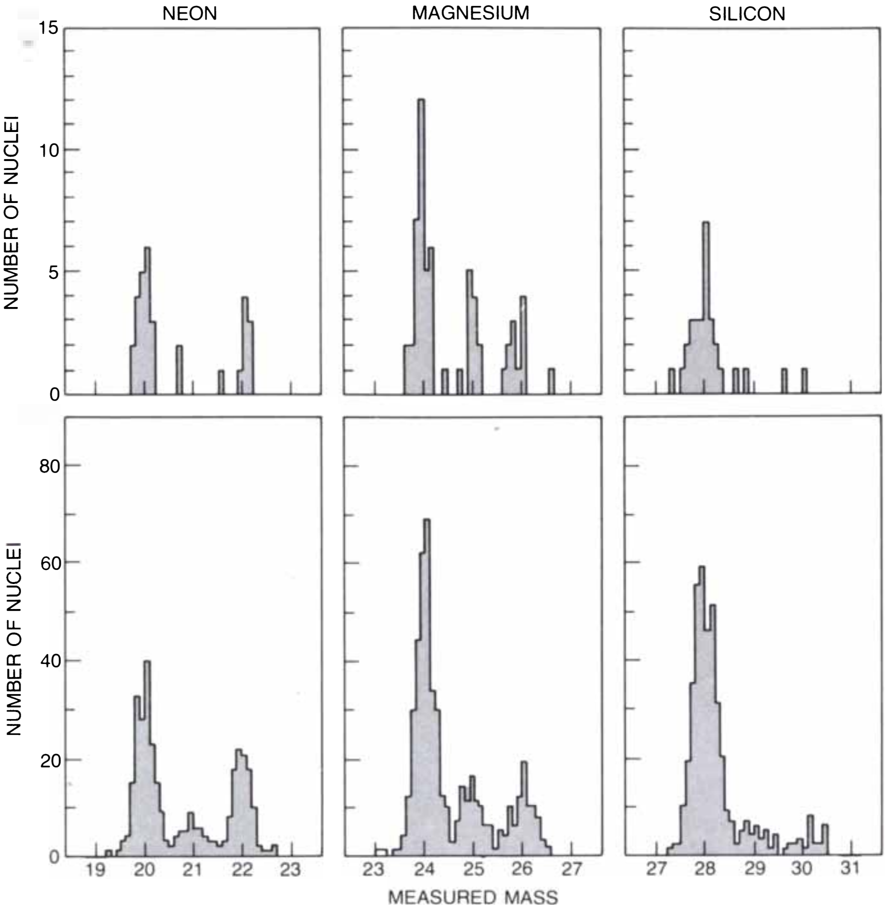
Elements are synthesized in stars when lighter nuclei fuse into heavier ones. Because the fusion process converts mass into energy when lighter nuclei are assembled into elements as heavy as iron, it is often described as a "burning" of the lighter nuclei. There are two distinct phases to the fusion process. The bulk of the heavy nuclei are formed by the slow, quiescent fusion of progressively heavier nuclei in ordinary stars, a process that releases thermonuclear energy over millions or billions of years.

A distinctly different type of nucleosynthesis operates in stars above a certain mass that have exhausted their supply of nuclei capable of releasing energy through fusion. Deprived of a continuing energy source, the star collapses and then explodes as a supernova. In this final explosive phase, fueled by the release of gravitational energy, a broad spectrum of heavy nuclei are synthesized, literally in a flash. The bulk of the star's mass is ejected and dispersed into the surrounding interstellar medium, leaving behind a dense, compact object such as a neutron star or possibly a black hole.

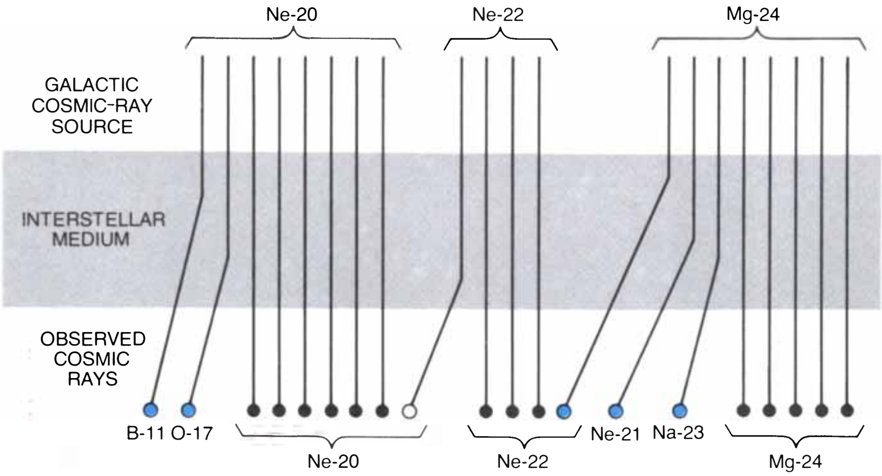
Since the quiescent and explosive phases of nucleosynthesis are characterized by quite different temperatures and time scales, they yield quite different nuclei. Most of the nuclei with an equal number of protons and neutrons are synthesized by a sequence of quiescent burning processes, beginning with the fusion of hydrogen nuclei (protons) into nuclei of ordinary helium, He-4. In such processes half of the protons are converted into neutrons by radioactive decays in which the positive charge on a proton is emitted in the form of a positron, or positive electron. Hydrogen nuclei also combine with any trace of carbon, nitrogen or oxygen (collectively referred to as CNO nuclei) that may have preexisted in the material out of which the star formed. For CNO nuclei to be present they must have been created in an earlier generation of stellar nucleosynthesis and injected into the interstellar medium that gave rise to the star. In the hydrogen-burning phase essentially all the carbon and oxygen nuclei are converted into ordinary nitrogen, N-14, by the series of nuclear reactions known as the CNO cycle.

Our sun is currently converting hydrogen into helium and will continue to do so for another five billion years. A more massive star will burn its hydrogen much faster because its interior temperature and density are higher. At the end of the hydrogen-burning phase the core of a massive star contracts, raising the temperature high enough to burn helium, yielding primarily carbon 12 and oxygen 16 through the fusion respectively of three and four helium nuclei. In this phase of the star's life cycle helium also combines with nitrogen 14 in a series of fusion reactions and subsequent radioactive decays whose end product is neon 22, a nucleus that has two more neutrons than it has protons.

The total number of extra neutrons in a star is significant because it governs the output of other neutron-rich nuclei synthesized in both the quiescent phase and the final explosive phase of a star's life. Neon 22 is derived from nitrogen 14, which in turn is derived from the original supply of CNO nuclei in the star, so that the abundance of neon 22 is proportional to the original abundance of CNO. For example, 2 percent of so-



DISTRIBUTION OF COSMIC-RAY ISOTOPES as determined in space by the Cal Tech spectrometer (*top*) and the Berkeley spectrometer (*bottom*) shows that neon, magnesium and silicon are each represented by their three stable isotopes. As in the solar system, the alpha-particle isotopes neon 20, magnesium 24 and silicon 28 are dominant. The 120 events in the Cal Tech sample were collected in the first $3\frac{1}{2}$ months of observation before the spectrometer was partially disabled. The 1,226 events in the Berkeley sample represent the data accumulated over a period of two years, after which the trajectory sensors failed. The Berkeley data are therefore given greater weight when the results are combined. The experiments were conducted by the authors and their colleagues, including Douglas E. Greiner and Harry H. Heckman of the Lawrence Berkeley Laboratory and John D. Spalding and Rochus E. Vogt of Cal Tech.



FRAGMENTATION OF COSMIC RAYS by collisions in the interstellar medium alters the composition of nuclei originally accelerated at the cosmic-ray source. Such collision fragments are called secondaries. The illustration shows some of the secondaries (*color*) that can result when primary nuclei of three isotopes (neon 20, neon 22 and magnesium 24) collide with atoms of interstellar gas. Isotopes such as boron 11, oxygen 17 and neon 21 are relatively rare among the products of stellar nucleosynthesis and can therefore be regarded as secondaries. Their abundance provides a key to the amount of fragmentation. With the exception of neon 21 three-fourths of the neutron-rich neon, magnesium and silicon nuclei are of primary origin.

lar-system material consists of CNO nuclei. Therefore a star originally supplied with a similar CNO abundance will end up with 2 percent of neon 22 in its core after the completion of hydrogen and helium burning. Although each neon-22 nucleus has a neutron excess of nearly 10 percent, the bulk of the matter will be carbon 12 and oxygen 16, nuclei with no extra neutrons, so that the overall neutron excess will be only .2 percent, corresponding to two more neutrons than protons for every 1,000 nucleons.

When the helium in the star nears exhaustion, the star again contracts and gets hotter, making possible the fusion of carbon and oxygen nuclei into nuclei such as neon 20, magnesium 24 and silicon 28, all of which have equal numbers of protons and neutrons and are the dominant isotopes of those elements. Such alpha-particle nuclei are the chief products of the quiescent phase of nucleosynthesis. Some neon 22 is also converted into magnesium 25 in this phase, freeing neutrons that can be captured by other nuclei to make additional neutron-rich isotopes.

As the core of a massive star becomes depleted of light nuclei capable of fueling quiescent burning, the star becomes unstable and a supernova explosion ensues, sending a shock wave from deep inside the star through the overlying matter and heating it to several billion degrees for a few tenths of a second. In this brief period many additional nuclei are synthesized, including magnesium 25, magnesium 26, silicon 29 and silicon 30. The amounts of these neutron-rich isotopes created are determined by the preexplosive abundance of neon 22, which is a source of extra neutrons. As a result the neutron excess originally fixed by the star's CNO abundance determines the proportion of neutron-rich nuclei that are synthesized in both the quiescent and the explosive periods of a star's life.

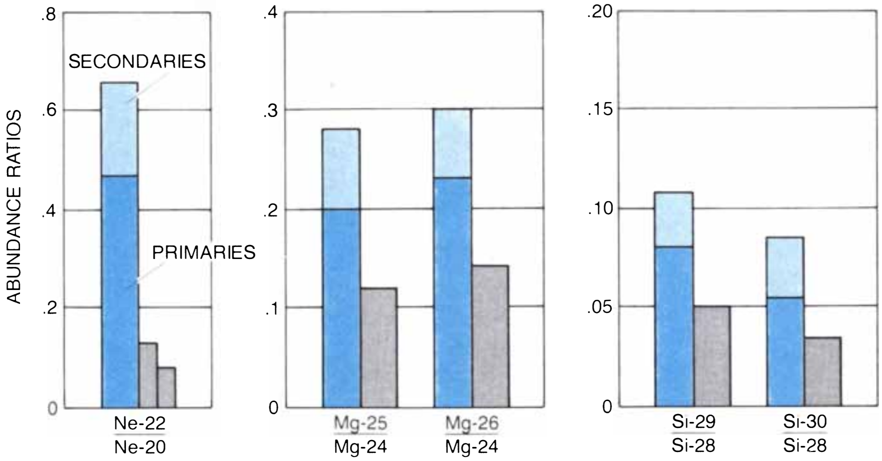
Some years ago W. David Arnett, who is now at the University of Chicago, suggested that the galaxy should exhibit a steady increase in the number of neutron-rich nuclei as a result of the cumulative effect of nucleosynthesis in successive generations of stars. Since the cosmic rays that reach the vicinity of the earth today are presumably a good deal younger than the five-billion-year-old material that forms the solar system, one might expect cosmic rays to reflect the increase in neutron-rich nuclei. Present models of galactic evolution suggest, however, that the expected enrichment of neutron-rich isotopes in the galaxy as a whole over the past five billion years may not be sufficient to explain our cosmic-ray observations, particularly in the case of neon 22.

More recently S. E. Woosley of the University of California at Santa Cruz and T. A. Weaver of the Lawrence Livermore National Laboratory have proposed that the observed excesses of neutron-rich isotopes in galactic cosmic rays might be explained if there are regions in our galaxy where the CNO abundance is significantly greater than it is in solar-system matter. Their calculations suggest that the material ejected from supernovas whose initial CNO abundance was 80 percent greater than it is in solar-system matter would be enriched by about 80 percent in neon 22 and by 50 to 70 percent in the abundances of each of the neutron-rich isotopes of magnesium and silicon. This model is supported by the nearly equal enrichments we find for four of the five neutron-rich isotopes. Therefore the 60 percent excesses of magnesium 25, magnesium 26, silicon 29 and silicon 30 can be adequately understood as resulting from an 80 percent increase in the CNO abundance in the regions where cosmic rays arise.

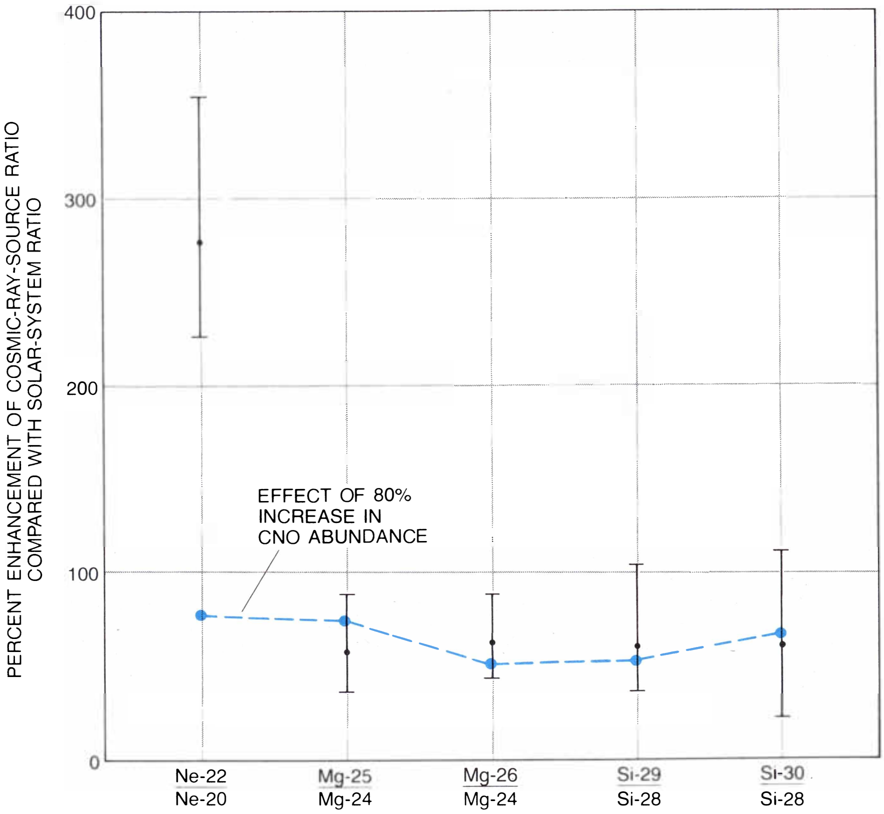
The excess of neon 22 that we find, however, is greater than 200 percent and is therefore at sharp variance with the 80 percent enhancement expected from an 80 percent increase in galactic CNO abundance. The observed neon-22 excess may result from some aspect of nucleosynthesis overlooked in simple models of galactic chemical evolution, but it may also result from a lack of understanding of the abundances of neon isotopes in solar-system material. For example, several distinct neon-isotope compositions have been measured in meteorites and in the sun.

Another possible explanation of the large excess of neon 22 in cosmic rays is that they may be coming not from a representative sample of interstellar matter but from a limited class of stellar objects that are synthesizing neon 22 with an abundance greatly in excess of that found in the solar system. A number of investigators have proposed models in which a large excess of neon 22 could be synthesized while a mixture of other nuclei almost like that of the solar system is maintained. It is not yet evident, however, that such sources could also account for the other isotope anomalies we have measured in magnesium and silicon.

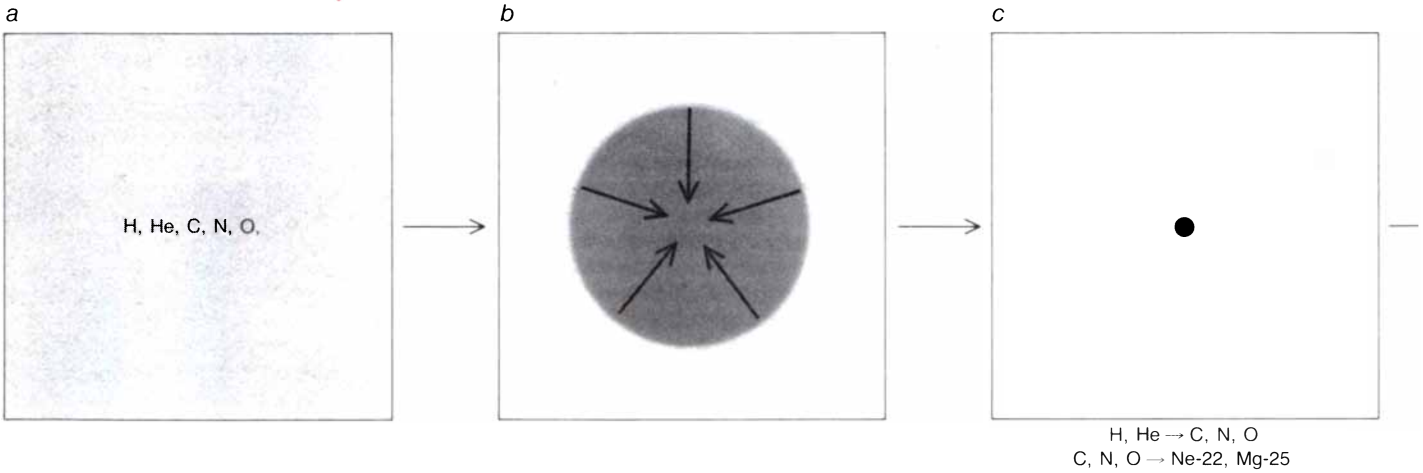
A more radical proposal has recently been put forward by K. A. Olive and David N. Schramm of the University of Chicago. They suggest that cosmic rays accurately reflect the composition of the interstellar medium of the galaxy at large and that it is the solar system that is atypical. They point to recent studies of meteorites indicating that when the solar system was formed, it contained a short-lived radioactive isotope of aluminum, Al-26. The existence of aluminum 26 is inferred from the presence in meteorites of its decay product, magnesium 26, in intimate association with stable



ABUNDANCES OF NEUTRON-RICH ISOTOPES in cosmic rays are plotted in color as ratios in which the more abundant alpha-particle isotopes of neon, magnesium and silicon serve as denominators. The corresponding abundances in solar-system material are gray bars. In the ratios for cosmic rays a distinction is made between primaries and secondaries. Since solar-system neon exhibits several isotopic abundance ratios, the range of variation is shown by two bars. The cosmic-ray measurements are the weighted mean of the Berkeley and Cal Tech results. They show that the source has an excess of the neutron-rich isotopes of these elements.



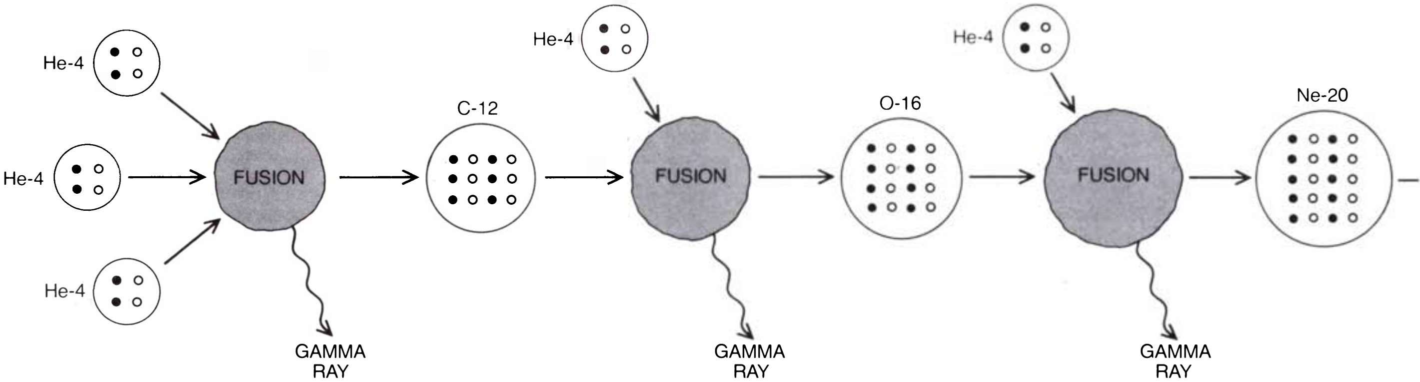
EXCESS OF NEUTRON-RICH ISOTOPES in cosmic-ray source material presumably reflects nucleosynthetic processes in stars whose initial composition differed from the composition of the generation of stars that supplied the material for the solar system. S. E. Woosley of the University of California at Santa Cruz and T. A. Weaver of the Lawrence Livermore National Laboratory propose that the excess of the neutron-rich isotopes can be accounted for if the stars responsible for the nuclei in cosmic rays initially had an 80 percent greater abundance of carbon, nitrogen and oxygen nuclei (collectively referred to as CNO nuclei) than the stars responsible for the nuclei in the solar system. The broken line in color shows the enhancement in neutron-rich isotopes of neon, magnesium and silicon expected in cosmic rays from such stars. The broken line passes through four of the five bars depicting the observed enhancement in cosmic-ray neutron-rich isotopes compared with those isotopes in the solar system. The ratio of neutron-rich neon 22 to neon 20, however, is off by more than 200 percent even if the maximum value for the solar system is taken as the basis for comparison. The vertical extent of the bars indicates the experimental uncertainties in the cosmic-ray observations.



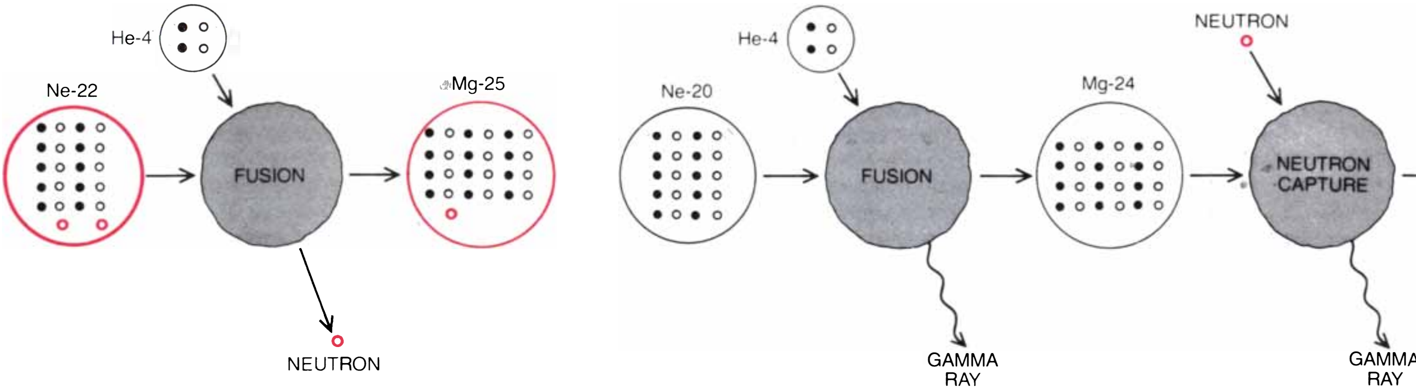
RELATIVE ABUNDANCES of isotopes in the galaxy are determined by the formation, evolution and explosive disruption of massive stars. In a region of the galaxy where the composition of the interstellar gas (*a*) is similar to that of matter in the solar system a cloud of gas collapses under the influence of its own gravity, giving rise to a new star (*b*). In the interior of the star thermonuclear fusion converts some of the original hydrogen and helium into alpha-particle nuclei such as carbon 12 and oxygen 16 (*c*). Simultaneously the CNO nuclei that were originally present in the stellar fuel are converted into heavier neutron-rich nuclei such as neon 22 and magnesium 25. When this quiescent burning has exhausted all the nuclear fuel in the core of the star, the star explodes as a supernova (*d*). The shock wave

aluminum 27. Aluminum 26 has a half-life of only about a million years, so that it could not have been present when the solar system condensed from the interstellar gas unless it had been recently created. The most likely explanation is that a supernova explosion injected the aluminum 26 just before the solar system formed. In that case other elements, also injected by the supernova, could have given the solar system a composition noticeably different from the composition of the average interstellar medium.

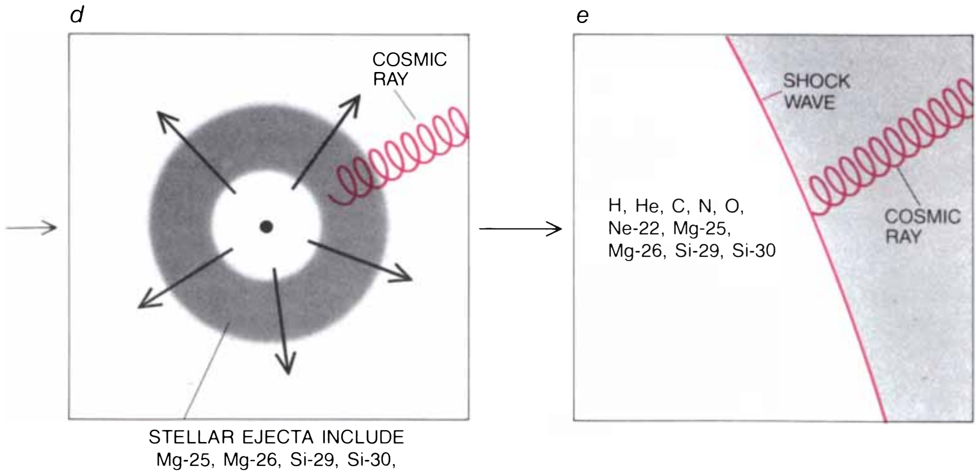
Olive and Schramm propose a specific model in which the concentration of neutron-rich nuclei typical of the interstellar medium at the time the solar system was formed was diluted by the injection of an excess of alpha-particle nuclei from a supernova source or sour-



QUIESCENT FUSION of the nuclei of light elements creates more massive nuclei. In the first stage (not shown) hydrogen nuclei fuse to form helium (alpha particles), and essentially all the CNO nuclei that may have been present in the original fuel charge are converted into nitrogen 14. The sequence at the left illustrates the second stage, in which helium nuclei fuse to form such alpha-particle nuclei as car-



EXPLOSIVE NUCLEOSYNTHESIS occurs during the supernova outburst of a massive star when the phase of quiescent burning has ended. The explosive shock wave heats the stellar material to several billion degrees Celsius for a few tenths of a second, initiating a complex array of nuclear reactions, a few of which are illustrated. The fusion of neon 22 and helium 4 (*left*) is particularly important because

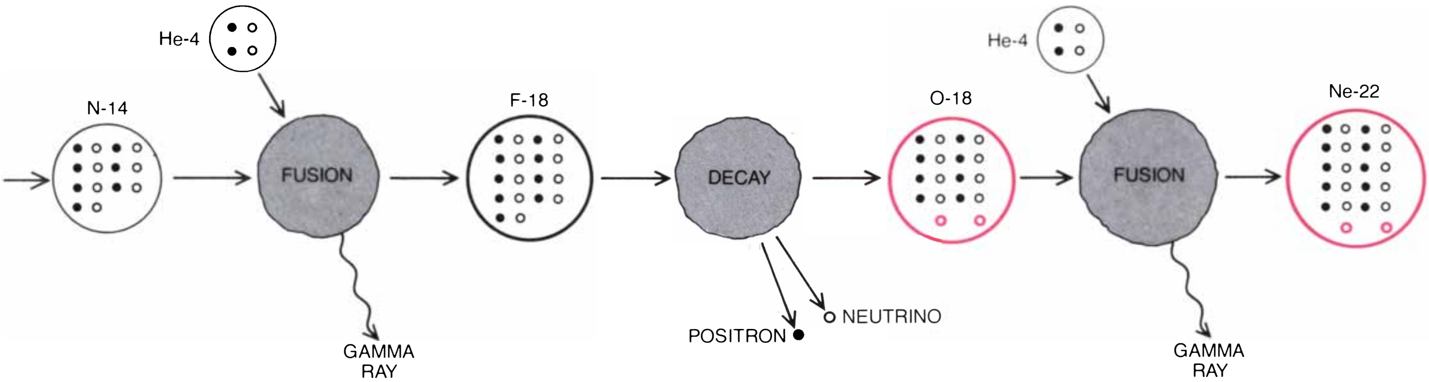


generated by the explosion synthesizes additional heavy nuclei and ejects most of the products of nucleosynthesis back into the interstellar gas. Repetitions of this sequence of events in successive generations of stars steadily enrich the interstellar gas in carbon, nitrogen and oxygen and in heavy nuclei with an excess of neutrons. Some of the nuclei in the gas are accelerated to cosmic-ray velocities, possibly by the shock waves from supernovas (*e*). Cosmic-ray acceleration could also occur directly as the supernova is ejecting matter into interstellar space (*d*).

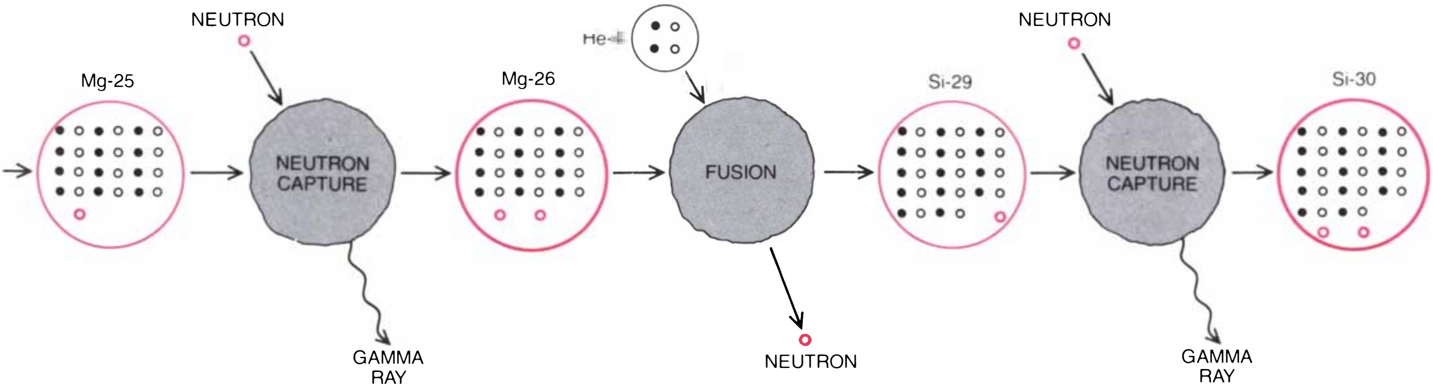
ces. These modified abundances would therefore be at variance with the abundances measured in cosmic rays, making the cosmic rays appear to be neutron-rich, in qualitative agreement with our observations. If Olive and Schramm are right, the real significance of cosmic-ray observations may lie in the light they throw on the events associated with the formation of the solar system.

As these various models and proposals show, the mixture of elements and isotopes in a sample of matter depends on the nature of nucleosynthesis in stars and on the history of star formation and evolution in the galaxy at large. Theoretical understanding of such processes is being advanced and deepened by detailed observations of the samples of matter that cosmic rays bring from other regions of the galaxy. The knowledge so far acquired is still very limited. The isotope abundances of only three elements—neon, magnesium and silicon—have been determined accurately in the cosmic-ray source, and in each case they have been found to differ from the corresponding abundances in solar-system samples. The anomalies observed to date may well be the rule rather than the exception.

A number of other elements, such as iron and nickel, have several stable isotopes whose abundances would serve as sensitive probes of nucleosynthesis. It is already known that the most abundant isotope of iron in both the solar system and cosmic rays is Fe-56. There is still no precise measurement, however, of the cosmic-ray abundances of two other isotopes of iron, Fe-54 and Fe-58, that are synthesized in different ratios under different stellar conditions. Instruments in future space vehicles, by measuring these and other isotopes with accuracy, should help to solve the riddles our observations have posed.



bon 12, oxygen 16 and neon 20. The sequence at the right depicts the fusion and radioactive-decay processes that convert nuclei of nitrogen 14 (which have been synthesized earlier from carbon nuclei) into nuclei of neon 22. Therefore the ultimate abundance of neon 22, which has two more neutrons than it has protons, depends on the initial abundance of carbon, nitrogen and oxygen in the star's fuel.



the neutrons released can be captured in the sequence of reactions (*right*) that yield neutron-rich isotopes of magnesium and silicon. The abundances of these isotopes are therefore determined by the supply of neon 22, which depends on the star's initial CNO abundance. Although a similar synthesis of neutron-rich isotopes proceeds in a quiescent burning phase, the reaction rates are then much lower.


FORD

The Interaction of Moving Water and Sessile Organisms

A host of marine organisms live attached to the bottom close to the shore. They show a remarkable array of adaptations to the forces exerted by strong currents and crashing waves

by M. A. R. Koehl

Anyone walking along an exposed rocky seacoast at low tide may notice that a remarkable number and variety of plants and animals live attached to the bottom and that they are often battered by waves. Such sessile organisms are at risk of being ripped away by the moving water, and yet they depend on the water to bring them nutrients, to carry off their wastes and often to disperse their offspring to new locations. How do they manage?

What one learns on examining sessile plants and animals closely, as I have been doing along the Pacific coast of North and South America and on Caribbean coral reefs, is that the organisms embody diverse compromises between maximizing and minimizing the effects of flowing water. Organisms living in a slow flow often have features that compensate for the lack of transport by moving water; for example, they can create their own feeding currents or tolerate low levels of oxygen. Similarly, organisms living in a fast flow often have features that enhance their ability to withstand and utilize the water rushing past them. The features that enable sessile organisms to stand in one place are more varied than one might expect.

A number of questions confront the investigator who wants to explore how a sessile organism deals mechanically with moving water. How does the structure of the organism affect the flow of water past it and the flow-induced forces on it? How does the organism's shape determine the stress on its tissues when it is subjected to flow forces? (Stress is the force or load per cross-sectional area of the material bearing the load.) How does the structural material of an organism affect the way it deforms or breaks in response to flow-induced stresses?

Sessile marine organisms live in several basic types of flow. There is a major distinction between intertidal and subtidal habitats, that is, the habitats between the low- and high-tide lines and the habitats seaward of the low-tide line. An intertidal plant or animal in a place where waves break on an exposed coast is subjected to a fast, turbulent flow. I have measured the flow over such organisms and found the velocity to be highest during the shoreward surge and seaward backwash just after a wave has broken.

For organisms living on the bottom in the high subtidal zone of a wave-swept shore the back-and-forth flow they encounter as waves pass overhead is slower. (Remember that the position of an organism with respect to the breaking waves, and hence the type of flow it encounters, changes as the tide rises and falls.) If an organism lives deeper than half the distance between the crests of successive waves passing overhead, it does not "feel" the waves. These organisms, as well as those living in protected bays and sounds, are exposed instead to steady currents or to the steady but periodically reversing currents of the tides.

What I have described so far could be called macrohabitats of flow. Each macrohabitat contains local microhabitats where the flow is different. To study a microhabitat one must take into account a basic feature of a fluid flowing over a solid surface: the flow is slowest nearest the surface. This layer of slowly moving fluid is known as the boundary layer; the slower the flow is or the farther one looks behind the leading edge of an object, the thicker the boundary layer is. Extremely small organisms (newly settled larvae and bottom-dwelling unicellular plants and animals) and flat encrusting organisms (crustose algae and some bryozoans, or moss animals) live in the boundary layer. The flow microhabitat of a short organism can be quite different from the mainstream flow over the area where it lives. Furthermore, the marine environment is generally not flat and smooth; the bumps and crevices and even the other organisms around a large plant or animal can markedly alter the flow past it.

Sea anemones of the genus *Anthopleura* provide good examples of animals living in surprising flow microhabitats. They are common on rocky shores from California to British Columbia. The great green anemone (*A. xanthogrammica*) carpets the bottom of intertidal surge channels at particularly exposed sites. Adhering to the bottom in the low intertidal zone, they live by ingesting mussels and sea urchins knocked down onto them by waves.

I have measured flows in the mainstream of such surge channels and flows down where the anemones are. In the mainstream the flow can be up to five meters per second on nonstormy days; at the tentacles of the anemones it is much slower. Great green anemones are as much as 20 centimeters (eight inches) across, but in an exposed channel they are pancake-shaped, with an average height above the rock of 2.5 centimeters (an inch). In other words, they avoid the fast flow by hunkering down.

Some great green anemones can also be found at more protected sites where the brunt of the waves is absorbed by rocks to seaward. In such a habitat the anemones stand at an average height of seven centimeters. Even though the mainstream flow at protected sites is much slower than it is in surge channels, the taller anemones stick up into the flow and therefore encounter velocities equal to or greater than those met by their short relatives in exposed channels.

Great green anemones at less exposed sites are often found side by side with smaller anemones of the species *Anthopleura elegantissima,* the aggregating anemones, which reproduce by splitting in two longitudinally so that they eventually cover the rocks with matlike clones. I found that the water passing these small, closely packed anemones traveled at only a tenth of the speed of

BELT OF SEAWEED along the rocky coast of central and southern Chile is exposed to heavy seas that impose strong forces on the tissues of a plant. The force is applied in one direction as a wave breaks and in the other direction as the water from the broken wave runs seaward. This seaweed is *Lessonia nigrescens,* which responds to the forces by bending with the flow. A companion seaweed in the belt, *Durvillea antarctica,* is pulled by the flow so that it lies more or less parallel to the sea bottom. The maximum stress in a stipe, or stem, of a seaweed pulled by the flow, as *D. antarctica* is, is considerably less than that in a stipe of a seaweed that bends, as *L. nigrescens* does.

GREAT GREEN ANEMONES, *Anthopleura xanthogrammica,* carpet the bottom of surge channels on exposed rocky shores. These anemones were photographed in such a channel on Tatoosh Island off the northwest tip of the state of Washington. In a surge channel the great green anemones, being sessile, cope with the strong flow by hunkering down close to the bottom, where the flow is slower than the mainstream flow. In a more protected place, where much of the force is absorbed by seaward rocks, *A. xanthogrammica* stands taller.

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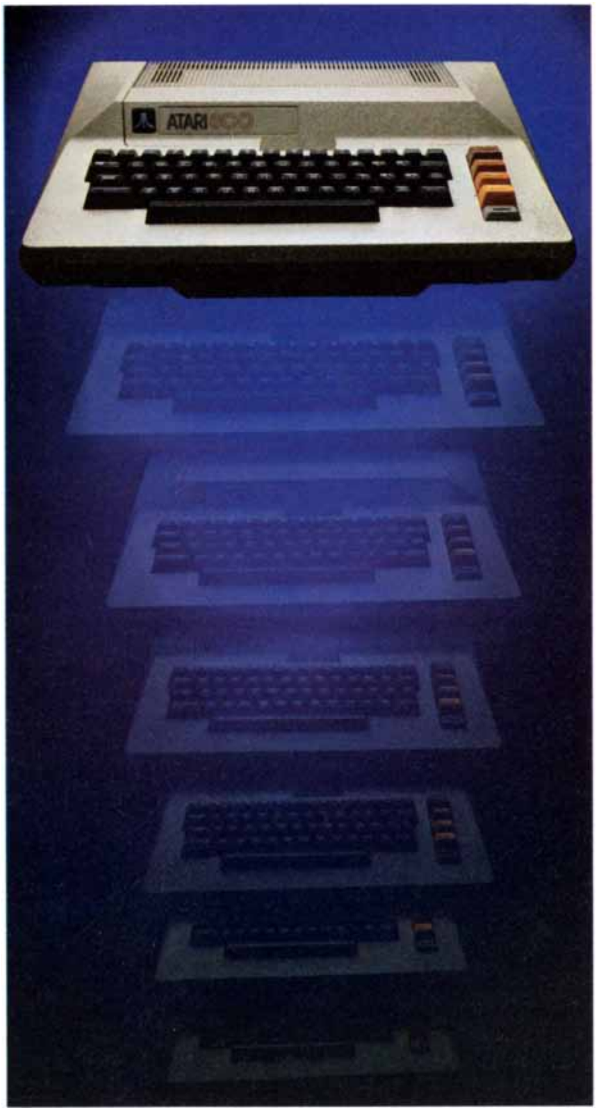

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the water passing a large, solitary great green anemone in their midst. The contrast indicates how different the flow microhabitats of organisms living side by side can be.

Many colonial marine animals, such as corals and hydroids, secrete a skeleton that supports the individuals of the colony (the polyps). The animals create the terrain on which they live and thereby modify their own flow environments. In order to visualize the flow around the branches of corals and models of corals John Chamberlain of Brooklyn College of the City University of New York and Richard Graus of Cleveland State University put dye in water. As one might expect, they found that the diameter, spacing and arrangement of the branches all affect the speed and direction of water movement within the colony. More surprisingly, they found that quite different colony configurations can give rise to the same pattern of flow over the polyps. The polyps of gorgonian sea whips and sea fans occupy flexible skeletons that sway back and forth as waves pass over them. Since the skeleton moves with the water, the flow with respect to the polyp can be low even though the colony lashes about in a habitat of heavy surge.

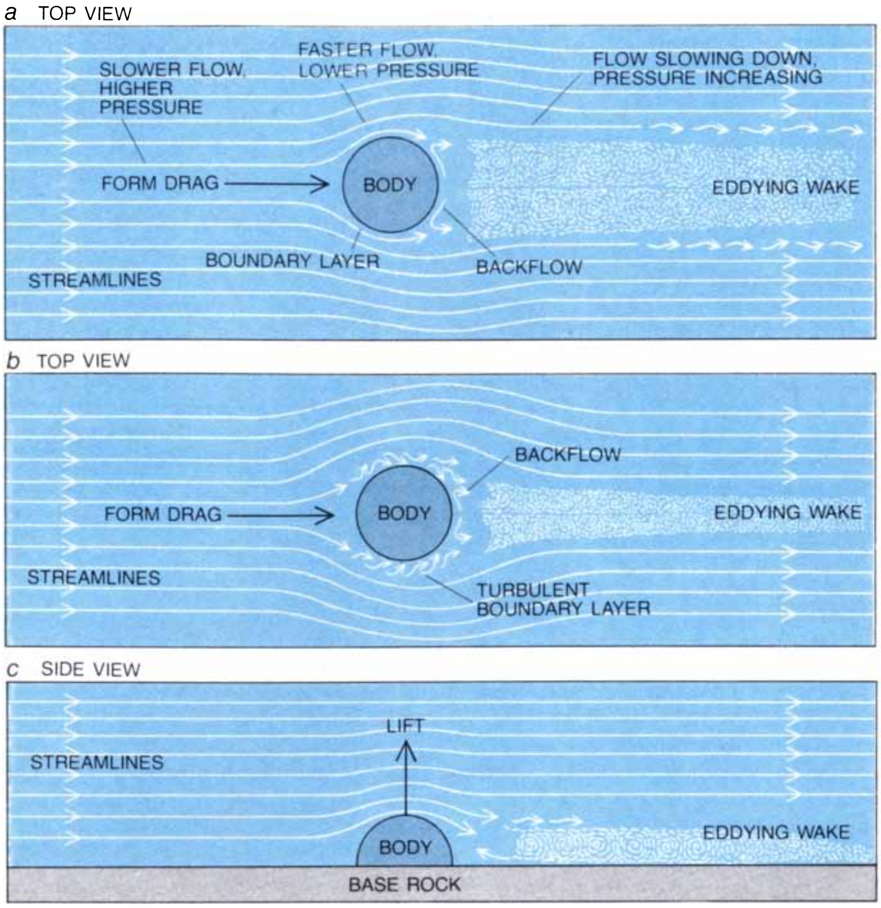
The shape, size and texture of a sessile organism affect the magnitude of the mechanical forces exerted on it when water flows across it. Drag forces, which tend to push an organism downstream, are due to the viscosity of water: the tendency of water molecules to resist sliding past one another. Water sticks to solid surfaces, including the surfaces of organisms, and a boundary layer of water around an organism is subjected to shearing forces as the flow passes by. Since water is viscous and resists being sheared, the result for the organism is skin-friction drag. The magnitude of the drag is proportional to the velocity of the flow and the length of the object and therefore gets larger as organisms increase in size or encounter faster flows.

The drag on small organisms in a slow flow is due mainly to skin friction. Large organisms in a fast flow are affected by an additional drag, called form drag, that is generally much stronger than skin friction. On the downstream side of an organism a turbulent wake forms. The pressure on the upstream side is greater than that on the downstream side, and so the organism tends to be pushed downstream. Any feature of an organism that reduces the size of the wake reduces form drag. The magnitude of form drag is proportional to the area of the body and the square of the velocity, and so a fairly small increase in length or velocity can lead to a comparatively large increase in form drag.

Several approaches are available to the investigator seeking to study how an organism's shape, surface texture and flexibility affect drag forces. One can compare the drag forces and the patterns of flow around similar organisms that differ in particular characteristics. One can also make models of the organisms, modifying various features in order to measure their effect on drag. Sessile organisms or models are attached to force transducers on the shore or in a flow tank or a towing rig, where the velocity of flow is controlled. Patterns of flow around the bodies are visualized with dye or marker particles or are measured by small electronic probes.

If a large organism has most of its surface parallel to the flow rather than at a right angle to it, it will create a smaller wake and therefore reduce form drag. This simple way of reducing drag is well illustrated by the forces on two species of large sea anemone: the squat great green anemone I have mentioned and the tall, fluffy species *Metridium senile,* which has a large, fluted crown of tiny tentacles that acts as a filter for catching zooplankton. The fluffy anemone lives subtidally, where the slow tidal currents bend its crown over at right angles to the flow. In contrast, the great green anemone stands with most of its surface area parallel to the flow. At a given velocity both the size of the wake and the amount of drag are greater on a fluffy anemone than they are on a great green anemone with the same diameter of crown.

The branches and tentacles of many flexible marine animals and plants are pushed together as the organism is bent over by flowing water. The movement puts the organism more nearly parallel



FLOW FORCES on a sessile marine organism are depicted schematically. As the velocity increases along a streamline (the path traveled by a particle of fluid) the pressure decreases, and vice versa. When water flows around the widest section of a body (*a*), its speed increases and the pressure it exerts on the surface of the body decreases. Beyond the widest section the fluid slows and the pressure rises. Viscosity causes fluid particles in the boundary layer (closest to the body) to lose momentum as they pass the body. When the flow over the body is fast enough and the body is large enough, this viscous retardation will stop the downstream progress of the water in the boundary layer, which may then be pushed upstream by the increasing pressure of the decelerating fluid around it. Behind the body a wake of eddying fluid separates from the mainstream flow, so that the pressure there is lower than it is at the front. This net downstream pressure is termed form drag. If the fluid is moving fast enough with respect to the body (*b*), the boundary layer becomes turbulent and momentum is transferred to it from the mainstream flow, giving rise to a smaller wake and less form drag. As the fluid moves faster across the top or one side of a body (*c*) the low pressure there tends to suck the body upward or sideways. The force is called lift but is not always upward; it can be at any right angle to the flow.

to the flow, reducing drag and the size of the wake. The fluffy anemone is an example: as the water flows faster the big tentacular crown collapses like an umbrella flipping inside out. A comparison of the drag on a fluffy-anemone model having a rigid crown with the drag on a model having a flexible crown reveals that the passive change of shape of the live anemone significantly reduces drag.

The drag forces on many large algae on wave-swept coasts are surprisingly low, notwithstanding the huge size of some of these seaweeds. Because of their flexibility the plants can be bent over parallel to the flow and are thus moved closer to the bottom, where the flow is slower. Flexibility also enables the seaweeds to employ another avoidance maneuver in waves. Since the plants move back and forth with the oscillating water, the water does not flow much with respect to them until they are completely flopped over in the direction of flow. The longer a seaweed is, the farther it is carried with the water before it is fully laid out in the direction of flow. If a seaweed is big enough, the water will start flowing in the opposite direction before the plant is fully bent over. Hence for large, flexible organisms in an oscillating flow an increase in length can lead to a decrease in drag.

Not all sessile organisms have drag-minimizing shapes. For example, certain gorgonian and alcyonacean corals form fan-shaped colonies that stand up at right angles to the direction of flow. These colonial animals feed on material suspended in the water passing them. The orientation of the colony in one plane perpendicular to the flow means not only that the colony is exposed to the maximum amount of flowing water per unit of time but also that it has no members downstream that would otherwise have to reprocess water depleted in food particles. Gordon Leversee, working at the Duke University Marine Laboratory, demonstrated that flat gorgonian corals captured more food when they were perpendicular to the flow than they did when they were parallel to it.

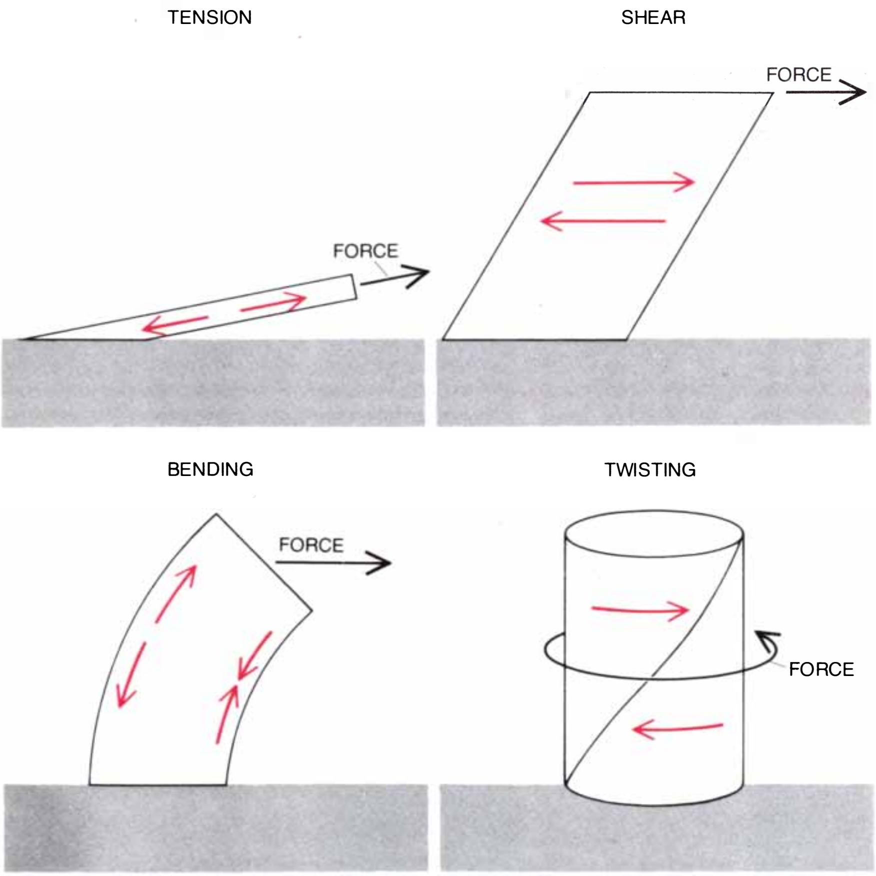
How do gorgonian sea fans achieve the correct orientation? Stephen A. Wainwright and John Dillon of Duke found that young sea fans are oriented every which way. They suggest that when moving water pushes on the growing fans, it tends to twist them until they are oriented perpendicular to the flow.

Sessile marine organisms in flowing water can also be subjected to lift forces. When the top surface of the organism curves upward, the water flowing over that surface must travel faster than the water flowing over other surfaces. The pressure in the fast-flowing region is lower than that in the other regions, and so the result is a force that tends to lift the organism off the substrate. Mark W. Denny of Stanford University has measured significant lift forces on various organisms, such as barnacles and limpets, that cling to rocks. By the same token, if the shape of an organism is such that the water flows faster around one side of it than around the other side, the organism is pulled toward the side where the flow is faster.

Still another force on many sessile organisms is the acceleration reaction. The water around a plant or an animal over which waves pass regularly speeds up, slows down and changes direction. The acceleration reaction pushes the organism in the direction in which the water is accelerating. (Bear in mind that when water slows down, it is accelerating in the direction opposite to its direction of movement.) The greater the volume of water that has to be accelerated to get around an organism, the stronger the acceleration reaction. A graph of the flow impinging on an organism in a wave shows that the maximum drag and the maximum acceleration reaction come at different times in the wave cycle. The force on an organism at any instant is the sum of the drag and the acceleration at that instant.

Examining the equations expressing the magnitude of the drag, lift and acceleration forces on sessile organisms, one can see that drag and lift are both proportional to the organism's area and that the acceleration reaction is proportional to the organism's volume. It would seem, then, that the acceleration reaction would become more important than drag or lift as an organism increases in size. Denny and Thomas Daniel of Duke and I suggest that acceleration-reaction forces may set an upper limit on the size many wave-swept organisms might achieve. Certainly many subtidal animals and plants, which live in slower and steadier currents than the intertidal organisms, do attain much larger sizes than the intertidal ones.

It may also be that wave action indirectly sets an upper limit on the size of certain organisms by restricting the amount of time the animals have to feed. Suzanne Miller of the University of Washington found that the force needed to dislodge various marine snails from a rock was smaller when they were moving over the surface than it was when they were still. If crashing waves cut short the time a snail has to move about and forage, the animal's growth may be limited. Similarly, the growth of an organism that feeds on particles suspended in the water may be limited if a violent flow makes it difficult for the organism to hold on to the food particles



EFFECTS ON THE TISSUES of a sessile marine organism from the forces set up by the flow of water are tension (when the organism is pulled), shear, bending and twisting. The black arrows show the load on the organism; the colored arrows show the deformation of its tissues.

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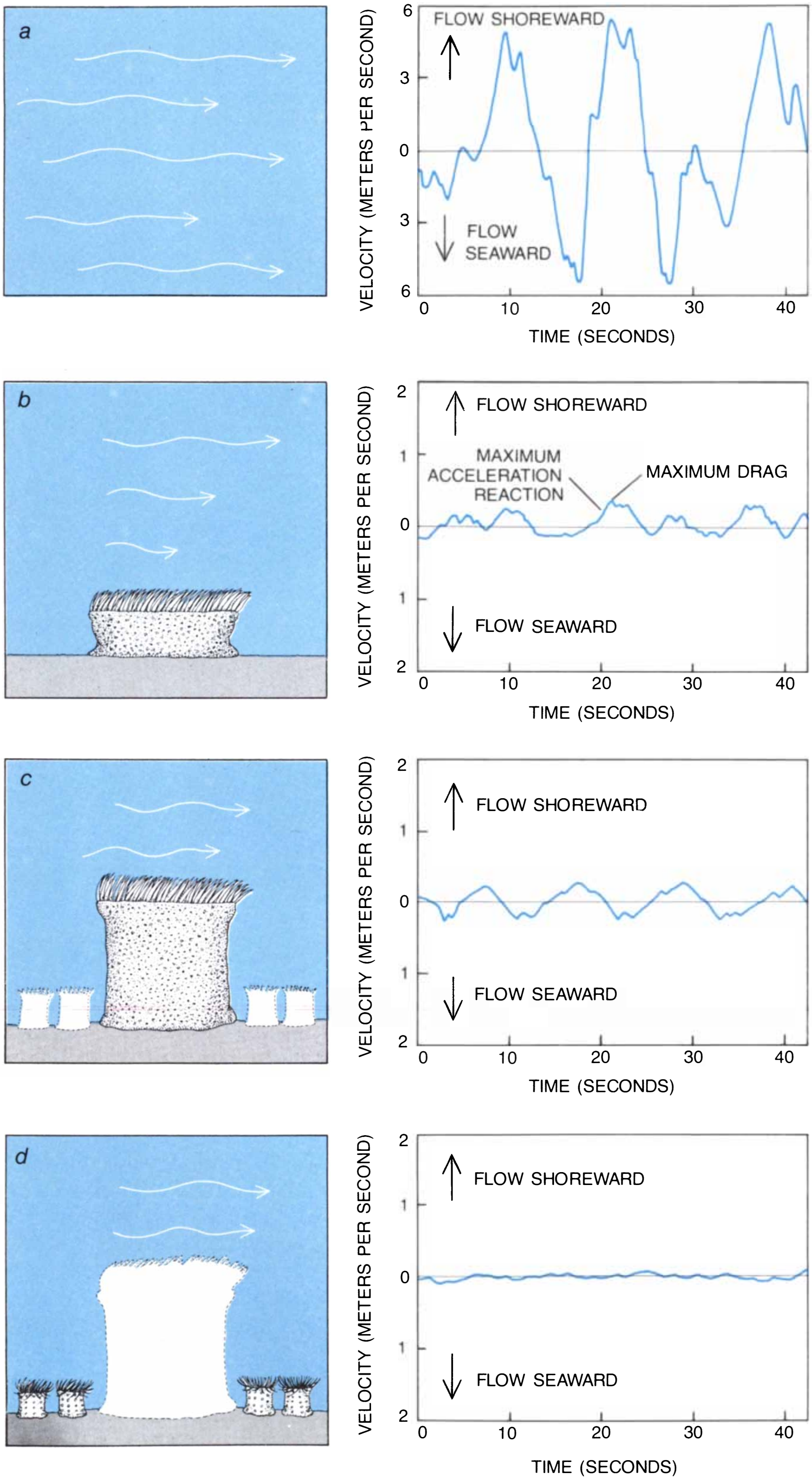


VARIATIONS OF FLOW around sessile anemones are charted. The flow of the mainstream in a surge channel (*a*) is often up to five meters per second as waves break on the shore and the water then retreats. A great green anemone in such a channel (*b*) assumes a flattened shape to take advantage of the lower velocity of flow near the channel bottom. The maximum drag force on the anemone is exerted when the water velocity peaks, whereas the maximum acceleration-reaction force is exerted when the acceleration is greatest. (The acceleration is high when the slope of the tracing of velocity over time is steep.) In a protected site (*c*), where the brunt of the waves is borne by rocks to seaward, a great green anemone extends farther into the flow. The flow past it is much the same as the flow past the anemone in the surge channel. Even less flow is felt by some aggregating anemones (*d*) near the green anemone in the protected site.

or makes the organism retract its delicate feeding structures.

Flow-induced forces sometimes deform or break an organism. Whether or not this happens depends on the magnitude of the stress (force per area) on the tissues of an organism in a flow and on the response of the tissues to the stress. The size and shape of an organism determine the magnitude of the stresses in its tissues when it bears a given load, such as a drag force. An attached plant or animal can bear the load in several ways, including tension, shear, bending and twisting.

When an organism is sheared or pulled, the stresses in its tissues are inversely proportional to its cross-sectional area but are independent of its length and cross-sectional shape. The stresses in the tissues of a narrow organism are greater than those in a wider organism bearing the same load.

When an organism is bent by a load, one side of its body is stretched and the other is squashed. The tissues on the upstream and downstream surfaces are respectively the most pulled and the most compressed. The magnitude of the tensile or compressive stress at a point in the body of such a sessile organism is inversely proportional to the distance of that point from the free end of the organism. If two organisms of the same diameter but different height bear the same bending load, the stresses are greater in the taller one.

The magnitude of the tensile and compressive stresses associated with bending is inversely proportional to the cube of the radius of the organism. Hence a small increase in radius can significantly decrease the stress. It is not surprising that many organisms that stand upright in a moving fluid are widest and most heavily reinforced near their base. It is also not surprising that narrow constrictions in the stems of sessile organisms function as flexible joints.

A small increase in the radius of an organism twisted by a given torque also leads to a large increase in the torsional shear stresses. A thin organism therefore twists more readily than a thick one. Moreover, a narrow waist in the stalk of an organism can act as a rotational joint.

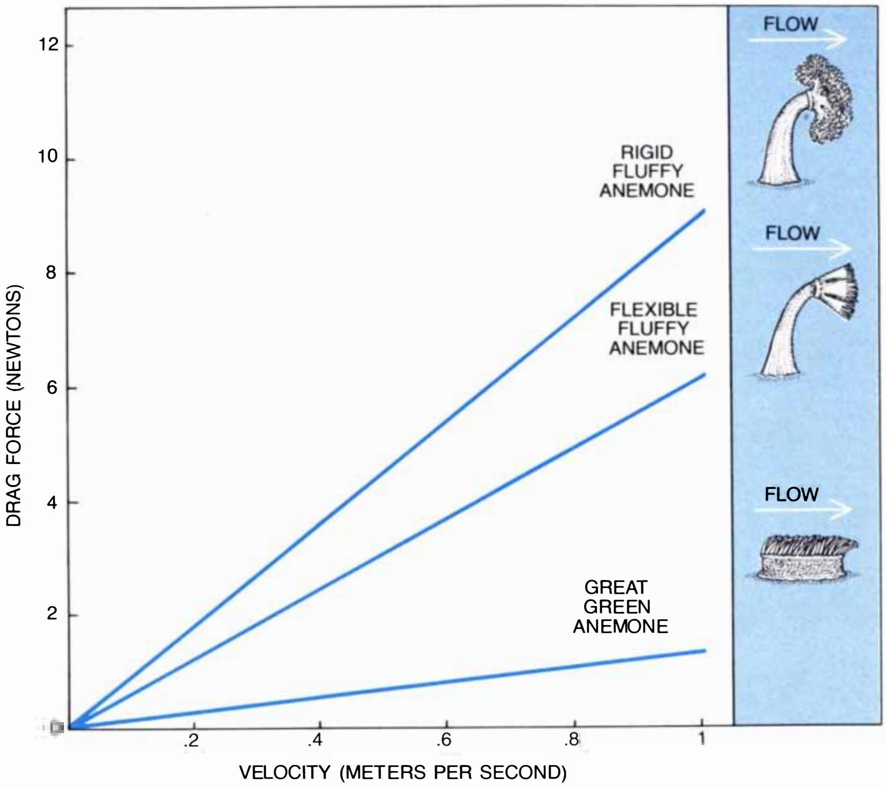
If you think about the large increase in stress in an organism that can accompany a small decrease in its radius, it becomes apparent the effect of a bite taken out of the stalk of a plant or an animal attached at a current-swept site can be potentially fatal. *Nereocystis leutkeana,* the giant bull kelp of the Pacific Northwest, provides a striking example of how disastrous the effect of such partial predation can be. Between 30 and 90 percent of the plants (depending on the location) that wash up on the shore have been broken at places in their stipes (stems) where only a small amount of tissue has been removed, usually by nibbling sea urchins.

The fluffy anemones and the great green anemones illustrate how profoundly the shape of an organism affects the stresses on it. The flow force on both the calm-water fluffy anemones and the surge-channel green anemones is about one newton (roughly a quarter of a pound) and tends to push the animals downstream. I have calculated, however, that under such a force the maximum stress in the tissues of a tall, slim fluffy anemone is 45 times greater than it is in an average short, wide green anemone. In other words, the fluffy anemone in the "protected" habitat is in a mechanically more stressful environment than the great green anemone in the "exposed" one.

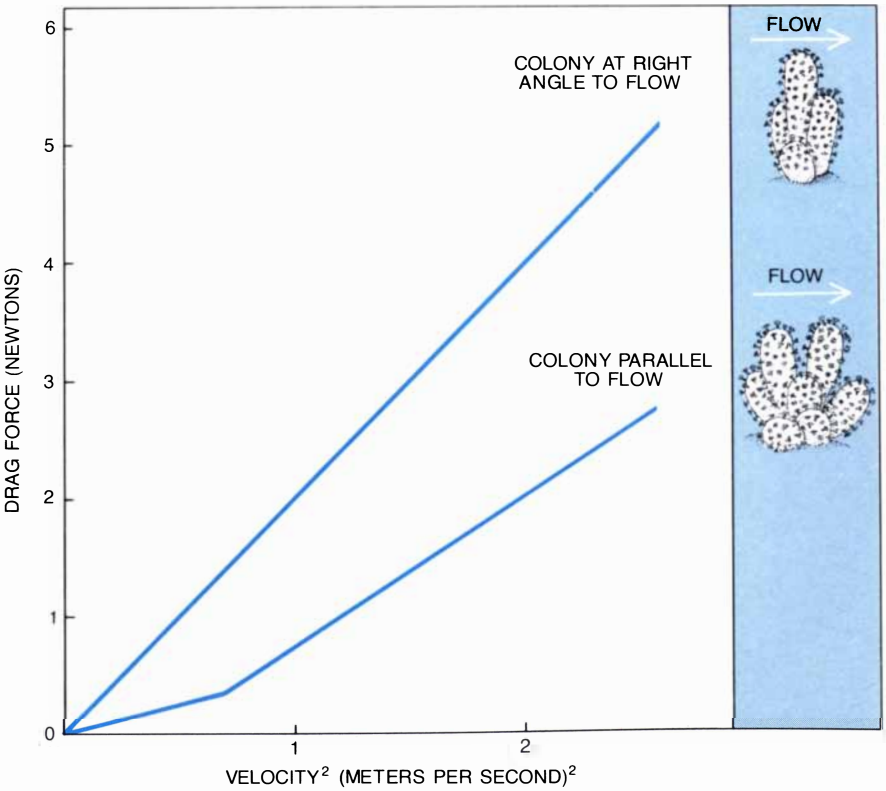
One can therefore see that a tall, narrow shape increases stress and a short, wide one decreases it. An organism can also reduce stress in its tissues by bearing loads in tension rather than by bending. An example is provided by two large seaweeds that form a dense band along the rocky shores of Chile. *Lessonia nigrescens* stands upright and is bent; *Durvillea antarctica* flops over at a narrow point near its holdfast and is pulled by moving water. I measured flow velocities of up to six meters per second across both species and forces of up to 20 newtons. A calculation of the maximum stress in a stipe 20 centimeters long and two centimeters in diameter, subjected to a load of 10 newtons, indicates that it is a third of a newton per square meter if the stipe is pulled (as *Durvillea* is) and more than 250 newtons if the stipe is bent (as *Lessonia* is).

The degree to which an organism deforms in flowing water depends not only on the magnitude of the stresses in its tissues but also on the stiffness of the tissues. Stiffness is measured by pulling a piece of tissue (in a device resembling a medieval torture rack) until it breaks. The apparatus measures both the force of the pull and the length to which the tissue has been stretched. A graph of the results shows that it takes more stress to pull a stiff tissue to a given extension than it does to pull a less stiff one. The slope of a stress-extension curve represents the elastic modulus of a material and provides a measure of the material's stiffness.

A peculiarity of many pliable biological materials is that their stiffness depends on the rate at which they are deformed (a dependence that does not hold with materials such as steel and glass). This characteristic is the basis of an interesting feature of the mechanical design of sessile organisms. As one might expect, a material deforms faster under a large stress than it does under a small one. The shape of an organism



WORK WITH MODELS shows that drag forces on anemones vary according to the configuration the animal presents to the flow of water. The drag on a model of a great green anemone, with most of its surface area parallel to the flow, is lower than the drag on the models of the fluffy anemone. The green anemone generates a smaller wake and so reduces form drag. The drag on a flexible model of the fluffy anemone, which, like the living animal, collapses into a more streamlined shape as the flow velocity increases, is lower than the drag on a rigid model.



DRAG FORCES on a colony of coral vary according to the orientation of the colony in the flow. The alcyonacean coral depicted here is *Alcyonium digitatum,* also known by the name dead-man's-fingers because it forms a fleshy colony that somewhat resembles a bloated hand.

determines the magnitude of the stress in its tissues, and the magnitude of the stress determines the rate of deformation, which in turn determines how stiff the material is. Therefore the shape of an organism can affect the stiffness of its tissues.

The fluffy sea anemone, *Metridium,* exemplifies how the stiffness of an organism's tissues is affected by the pace of its life. A tissue can be subjected to a creep test in which a constant stress is applied and the deformation over a period of time is measured. Sea anemones consist primarily of the gelatinous tissue called mesoglea. A graph of a creep test for mesoglea of *Metridium* shows that the tissue deforms little if it is pulled for less than a minute. The result corresponds to the time scale of the animal's muscular changes of shape. Hence the mesoglea provides a reasonably stiff support for the muscles and skeletal elements of the organism to work against.

Consider now a stress applied for several hours, the duration of the tidal currents pushing on the anemone. The mesoglea stretches increasingly and the anemone is bent passively in the direction of the flow. Over a period of between 12 and 24 hours the mesoglea can be stretched to three times its original length, even by small stresses. This long period corresponds to the time it takes for a fluffy anemone to inflate itself to the large sizes it can attain. (It does so by taking in water through grooves called siphonoglyphs, through which the water is pumped by beating cilia.) To a muscle working quickly the mesoglea is relatively stiff, but to a siphonoglyph working slowly it is quite compliant.

The creep curve for a piece of mesoglea from a great green anemone is notably different. Even if this anemone is beaten on by waves all day in a surge channel, it does not stretch much. The mesogleas of the two species of anemone show structural and molecular differences reflecting adaptations to the different mechanical conditions in their habitats.

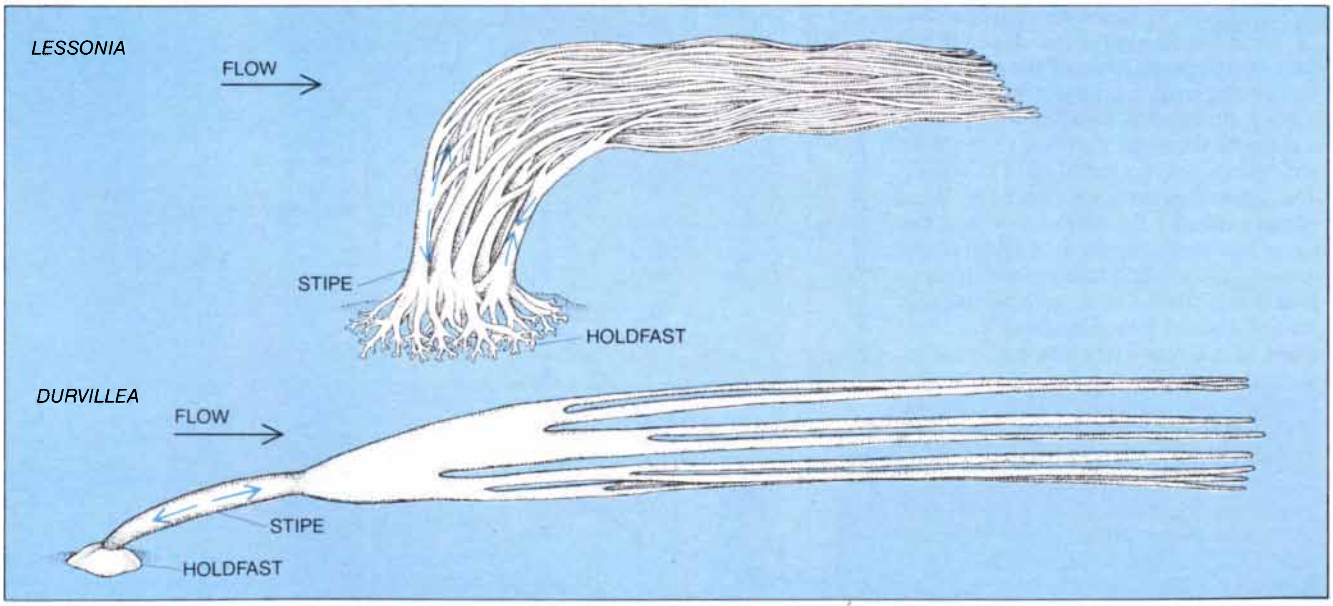
The supporting stalk of many attached plants and animals consists of more than one type of material. If the stiffest material is near the center of the stalk, the structure is more flexible than it would be if the material were at the periphery. Stephen Wainwright and I studied an example of a structure so flexible that it can easily be tied in knots without deforming. It is the stipe of the bull kelp, *Nereocystis.* The tissue near the center of the stipe is stiffer than the tissue at the periphery. This not only puts the main load-bearing tissue where it is less likely to be munched by sea urchins but also provides the flexibility that allows the kelp to be pushed over parallel to a fast current, reducing drag. In contrast, the stems of many terrestrial plants that stand upright (sunflowers, for example) have stiff vessels at their periphery.

The extent to which a sessile organism deforms in the water flow of a particular habitat has important effects on the success of the organism in its daily activities. Can it keep its tentacles in the appropriate configuration to catch food particles? Can it hold its photosynthesizing surfaces up above those of its competitors? Is it at risk of being injured or ripped from its substrate by the flow?

Whether or not a sessile organism will be broken away from its substrate depends not only on the magnitude of the stresses it encounters but also on the strength and toughness of its tissue and of the glue that holds it to the bottom. The strength of a material is defined as the stress required to break it. The likelihood that something will be broken by a wave or a current, however, depends on its toughness: the work required to break it. Glass may be stronger than leather, but a shoe is harder to break than a vase because leather is tougher than glass. The area under a stress-extension curve for a specimen that has been pulled until it breaks represents a measure of the work per volume of material necessary to achieve the break, that is, a measure of the toughness of the material.

A set of such curves reveals that there is more than one way to be tough. For example, the stiff, strong material from the stipe of the seaweed *Lessonia* is no tougher than the more compliant stipe of the seaweed *Durvillea.* These two algae illustrate two quite different strategies for resisting breakage. One is to be stiff and strong, as *Lessonia* is; the other is to be a "weakling" and to deform under stress, but to be able to extend a great deal before breaking, after the manner of *Durvillea.*

If a weakling is stressed for a long enough time to be stretched out to the breaking point, it will break at a lower stress than an organism that is stiff and tough. The weakling pattern of toughness is therefore more effective for organisms subjected to pulsing forces of



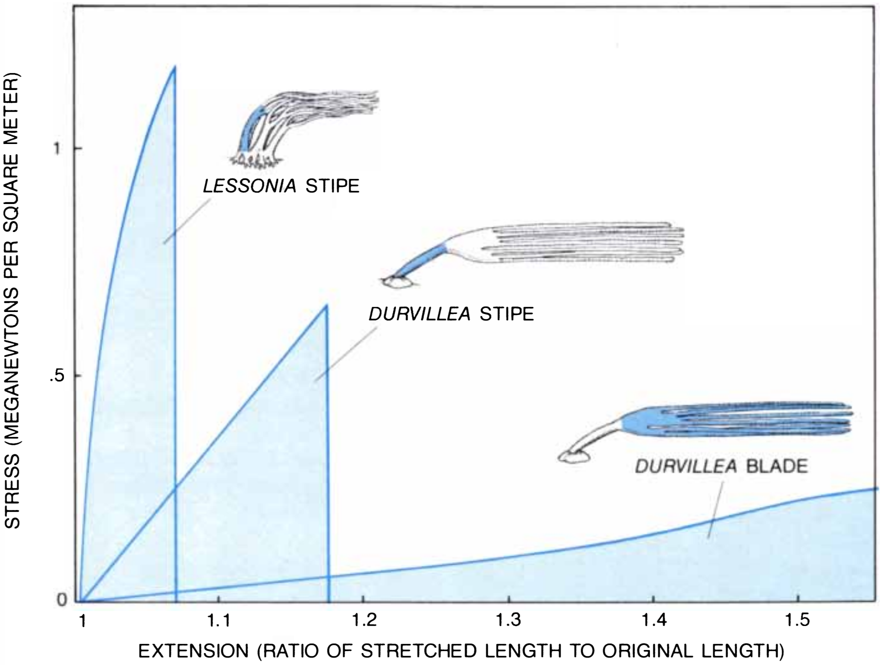
STRESS ON TISSUES of a sessile marine organism can be reduced if the organism bears loads in tension rather than by bending. Examples are provided by two large seaweeds that form a dense band along the rocky shores of Chile. *Lessonia nigrescens* is bent by moving water so that one side of its stipes is bent and the other is compressed; the maximum tensile and compressive stresses in a stipe are proportional to the length of the stipe and inversely proportional to the cube of its radius. *Durvillea antarctica* is pulled by moving water. The tensile stress in a stipe is independent of length and proportional to the square of the radius. The colored arrows represent the stresses.

short duration, as on a shore beaten by waves. A weakling must also be resilient to survive: it must be able to recover to its resting shape before the next wave arrives. Many stretchy algae are highly resilient. For example, the stipe of the kelp *Nereocystis* can store as strain energy, and can employ for elastic recoil, about 75 percent of the energy that goes into stretching it. This stipe material is as resilient as elastin, the rubbery protein that enables human arteries to snap back into shape after each pulse of blood pumped by the heart.

I have designed mechanical tests to simulate the stresses sessile marine organisms encounter in nature. Compared with barnacles and stony corals, sea anemones are definitely in the weakling class; nevertheless, my simulation tests on mesoglea from the great green anemone of a surge channel indicate that this tissue is restored to its resting shape wave after wave. The mesoglea of the calm-water fluffy anemone does not recover as fast under the same stress, and after many cycles it can become so stretched out that it breaks. The fluffy anemone is a weakling-class organism that apparently lacks the resilience to survive in a surge channel.

A number of marine ecologists have described how physical disturbance is one of the important factors affecting the diversity of communities of sessile organisms. The patches of substrate cleared when organisms are broken away can be colonized by different plants and animals that might otherwise be excluded from the habitat by competitively more successful organisms. Those of us who studied the coral reefs of Jamaica before and after they were ravaged by Hurricane Allen in 1980 have a vivid picture of the role violent water motion can play in altering a community of organisms. As you might expect from my comments on the physical characteristics of sessile marine organisms, the tall, rigid corals of the reefs were smashed in the hurricane, whereas the lacy, flexible sea fans and the low-lying matlike algae survived (unless they were scraped away or buried by the rubble of the coral).

Books could be filled with examples of the weird and wonderful features of marine organisms that enable them to withstand and utilize moving water. The examples I have cited should illustrate that the marine biologist, armed with a few basic physical rules, can make considerable progress toward understanding the physical performance of organisms of different construction in different habitats. An exciting area that is just beginning to be explored is the role mechanical forces might play in the growth and development of organisms, perhaps helping to mold their bodies into the beautifully "engineered" adult forms seen in such abundance on shorelines and reefs.



TOUGHNESS OF TISSUE can be measured by calculating the area under a stress-extension curve of a tissue pulled until it breaks. The area represents the work per volume of material that is required to break the specimen. The calculations reveal there is no significant difference in the amount of work (74 kilojoules per cubic meter) required to break the tissues of the strong stipe of *Lessonia,* the more elastic stipe of *Durvillea* or the extensible blade of *Durvillea.* The measurements show that sessile marine organisms have more than one way of being tough.

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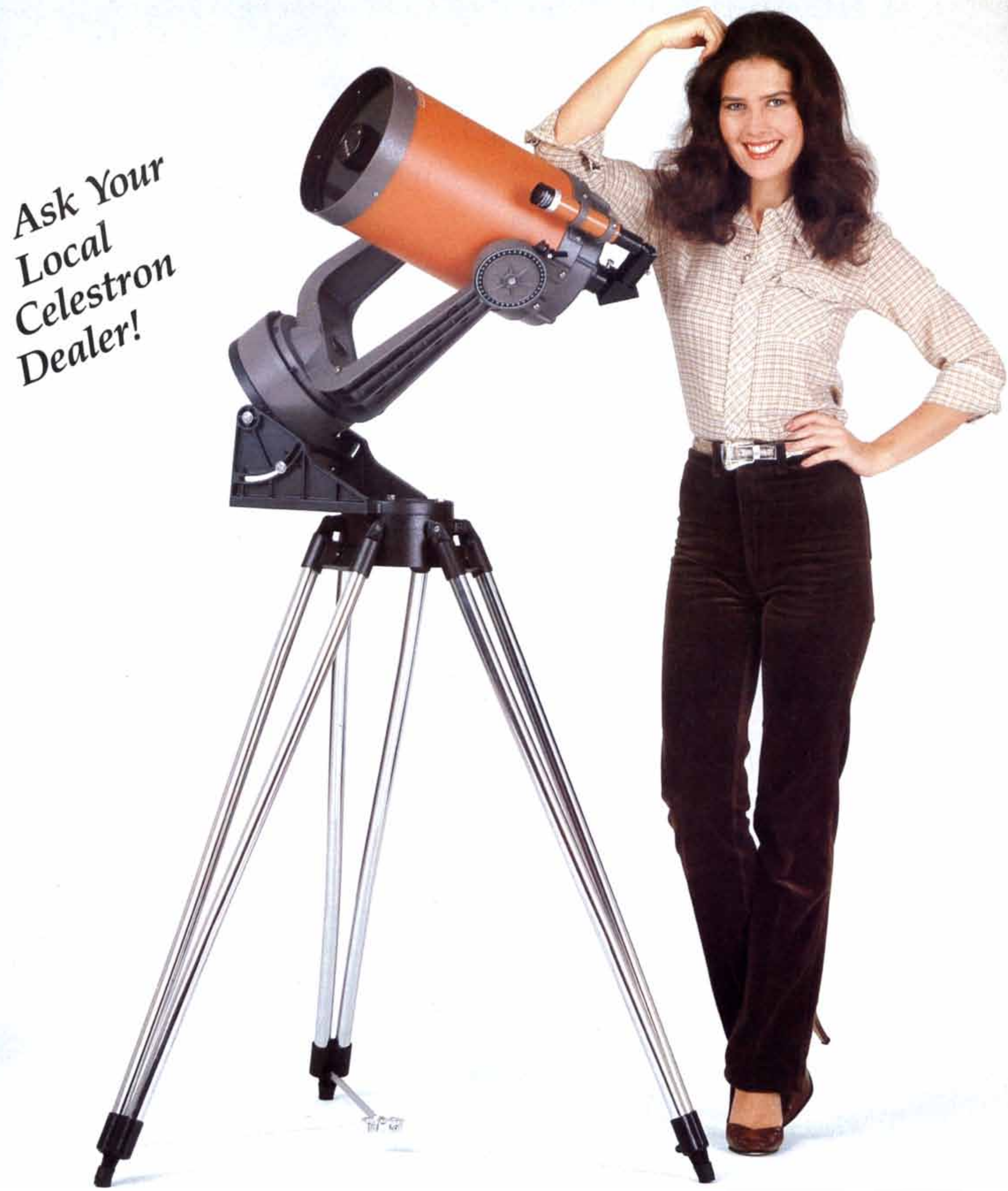

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The Search for Prime Numbers

Until recently the testing of a 100-digit number to determine whether it is prime or composite could have taken a century even with a large computer. Now it can be done in a minute

by Carl Pomerance

The prime numbers are the multiplicative building blocks of the number system. If a number is prime, there are no smaller natural numbers that can be multiplied to yield it as their product. The prime number 11, for example, cannot be broken down into smaller factors; only 1×11 is equal to 11. If a number is composite, on the other hand, it can be expressed as the product of two or more prime factors. The composite number 12 is equal to $2 \times 2 \times 3$. Every whole number larger than 1 is either a prime or the product of a unique set of primes. This fact, which was known to the ancient Greeks, is so central to the system of natural numbers that it is called the fundamental theorem of arithmetic.

How can one determine whether a number is prime or composite? The most straightforward way is to divide the number to be tested by the integers in sequence: 2, 3, 4 and so on. If any of the divisions comes out even (that is, leaves no remainder), the test number is composite and the divisor and the quotient are factors of the number. If all the integers up to the test number are tried and none of the divisions comes out even, the number is prime. Actually it is not necessary to continue up to the test number; the procedure can be stopped as soon as the trial divisor exceeds the square root of the test number. The reason is that factors are always found in pairs; if a number has a factor larger than the square root, it must also have one smaller.

Stopping the trial division at the square root can greatly speed up a test for primality, and there are other short cuts, such as deleting all the even trial divisors after 2. Nevertheless, the trial-division algorithm is utterly incapable of testing the largest primes known. Consider the 13,395-digit number $2^{44,497} - 1$, which was proved to be prime in 1979 by Harry L. Nelson and David Slowinski of the Lawrence Livermore Laboratory. If a computer were to carry out trial divisions at the rate of a million divisions per second, and if it were to stop once it reached the square root of the number, it would need $10^{6,684}$ years to finish the task.

The trouble with the trial-division method is that it does far more than is required: trial division not only decides whether a number is prime or composite but also gives factors of any composite number. Although there are methods of factoring that do not depend on trial division, none of them can factor an arbitrary number having a "mere" 100 digits in any reasonable time, even with a large computer. It turns out, however, that it is possible to determine whether or not a number is prime without necessarily finding any factors in case the number is composite. If the number has no small factors, such methods are almost invariably more efficient than the methods that give the factors. In the past two years a method has been developed that enables a computer to determine the primality of an arbitrary 100-digit number in about 40 seconds of running time.

The problem of testing for primality and the superficially related problem of factoring are classic problems in the theory of numbers, the branch of mathematics that deals with the properties of whole numbers. Number theory is rich in problems that are tantalizingly simple to state but notoriously difficult to solve. Number-theory problems having to do with primality have been a source of fascination to mathematicians at least since Euclid.

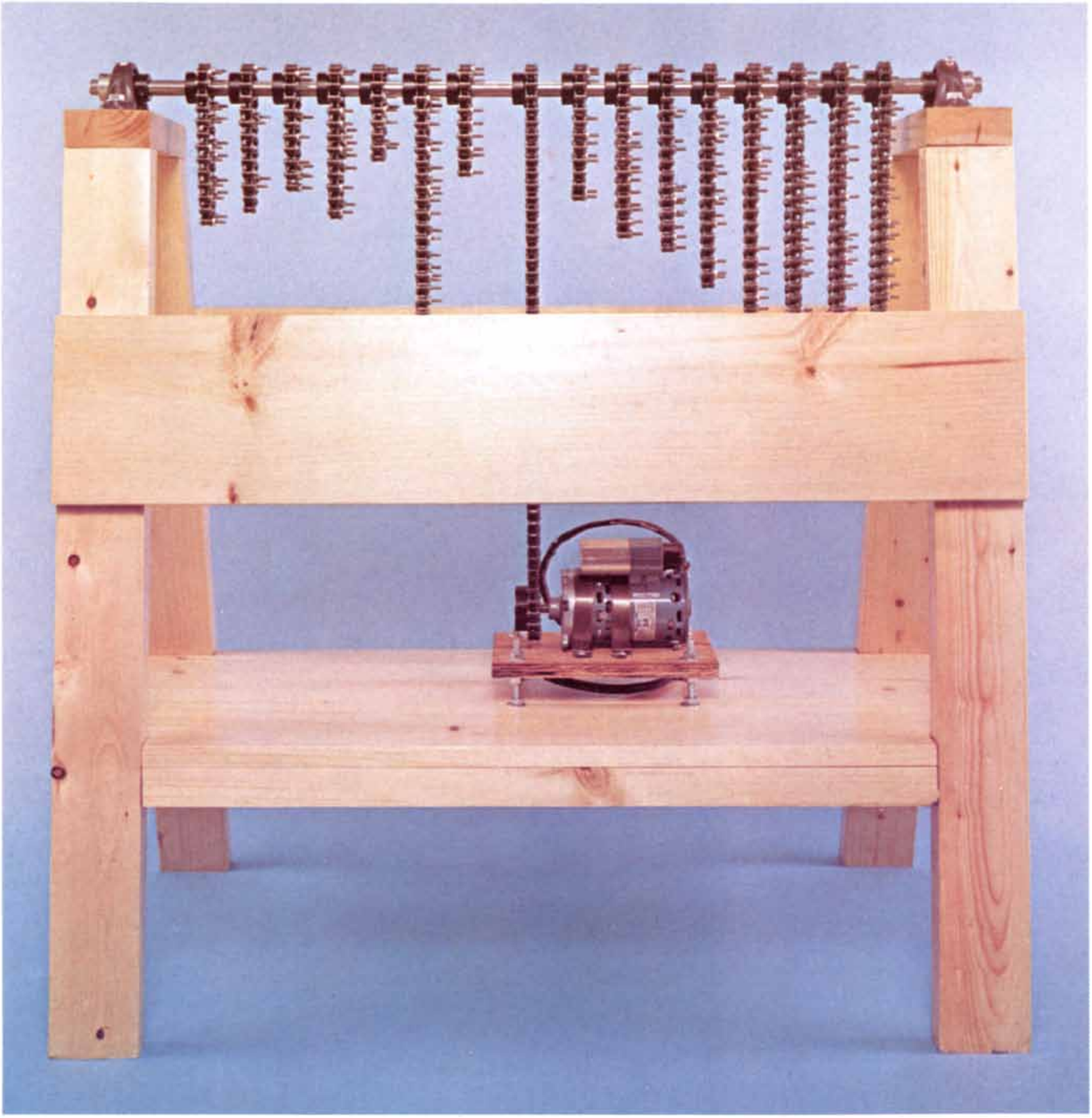
For example, there appear to be infinitely many prime twins, which are pairs of primes such as 17 and 19 that differ by 2, but the conjecture has not been proved. It is almost certainly true that there is always at least one prime between the squares of consecutive integers, but the statement also stands unproved. Christian Goldbach conjectured in 1742 that every even number after 2 is the sum of two primes; 32, for instance, is the sum of 13 and 19. Goldbach's conjecture too has resisted all attempts at proof, although in 1937 the Russian mathematician I. M. Vinogradov showed that all "large enough" odd numbers can be expressed as the sum of three primes. Vinogradov was not, however, able to state explicitly what is meant by the term "large enough."

A corollary of Vinogradov's theorem is that all large enough even numbers can be expressed as a sum of four primes; according to the theorem, it is always possible to represent the odd number that is three less than any large enough even number as a sum of three primes. The even number is then the sum of the three primes and the prime number 3. In 1966 the Chinese mathematician Chen Jing-run showed that all large enough even numbers can be expressed as the sum of a prime number and a number that is either prime or the sum of two primes. Such approximations to Goldbach's conjecture are deep results in the sense that their proofs call for advanced mathematical analysis and are quite difficult.

There are also many statements about primes that can be proved by elementary methods, and many of the proofs are delightfully ingenious. For example, it was known by Euclid that the number of primes is infinite. The argument is indirect: it is assumed that the number of primes is finite, in which case there must be some largest prime, and from the assumption a contradiction is derived. Suppose the largest prime is p. Then consider the number N, defined as the product of all the prime numbers from 2 to p. The number $N+1$ must be either prime or composite. $N+1$ is greater than p, and so according to the original assumption it must be composite; otherwise it would be a prime larger than p. Since $N+1$ is composite, the fundamental theorem of arithmetic implies that it has prime factors. Because of the way $N+1$ was constructed, however, it leaves the remainder 1 when it is divided by any prime from 2 to p. Its prime factors (if it has any) must therefore be larger than p. Again the assumption that there is some largest prime leads to a contradiction, and so there can be no upper limit on the set of primes.

In a similar spirit it is easy to prove that consecutive primes can be as far apart as one might want. Consider the sequence of numbers $n! + 2$, $n! + 3$, $n! + 4, \ldots, n! + n$, where $n!$ (read n factorial) is the product of all the whole numbers from 1 to n. Note that $n! + 2$ is evenly divisible by 2, $n! + 3$ is evenly divisible by 3 and so on; finally, $n! + n$ is evenly divisible by n. Hence all $n - 1$ numbers in the sequence are composite. The sequence can be made as long as one likes simply by picking a large enough number n.

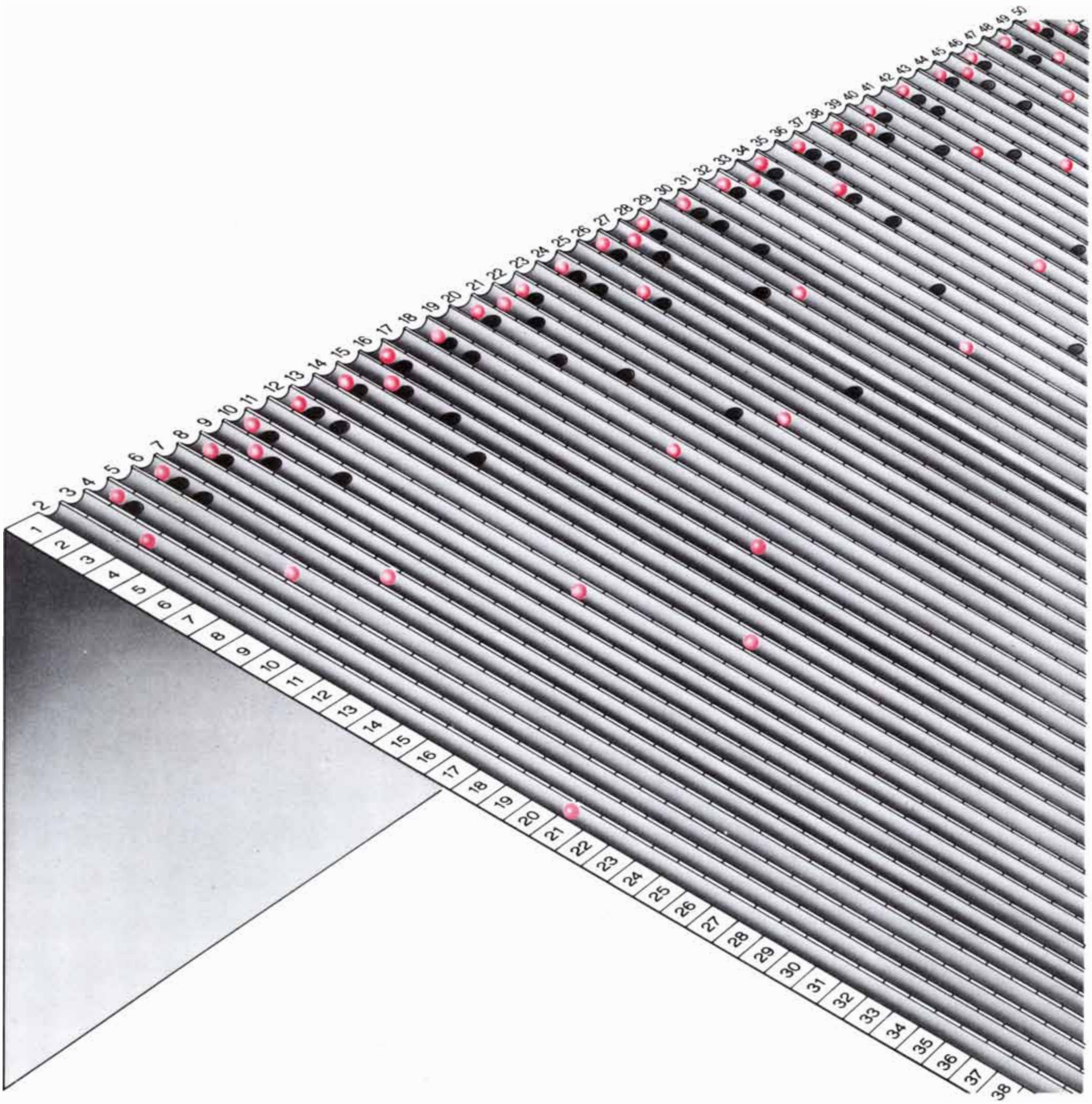
Many mathematicians have regarded number theory as "the queen of mathematics," partly for the intricate beauty of its proofs but also because there has long been the feeling that its study is a form of pure contemplation, unburdened by the potential for practical consequences. Since 1977, however, the development of number theory has also been stimulated by the recognition that



EARLY MACHINE for the exploration of the number system was built in 1926 by D. H. Lehmer of the University of California at Berkeley. Constructed out of a sawhorse, bicycle chains and other readily available materials, the machine was a special-purpose computer that could be programmed to search rapidly for numbers having the special form necessary for solving certain problems in number theory. Primality testing, that is, the classification of a number as being either prime or composite, is one of the most important of these problems. (A prime is a number evenly divisible only by itself and 1; if a number has other divisors, it is composite.) The conditions that must be met by a numerical solution to a problem could be programmed on Lehmer's machine by inserting bolts into certain links of the bicycle chains. When the chains were turned by a motor, the machine would run until all the bolts were lined up; the motor was then automatically turned off. The number corresponding to the configuration of the chains at the stopping point would satisfy the conditions programmed. Lehmer built several faster versions of the machine, but the 1926 version has since been destroyed. The machine in the photograph is one now being built by Roberto Canepa of Carnegie-Mellon University at the Computer Museum in Marlboro, Mass.

it could have an important application to cryptography, the study of secure communication. In that year Ronald L. Rivest of the Massachusetts Institute of Technology, Adi Shamir of the Weizmann Institute of Science and Leonard M. Adleman of the University of Southern California pointed out that a public-key cryptographic system could be based on the difficulty of factoring a large composite number that is the product of, say, two 100-digit primes.

In a public-key system the means of encoding the message can be made public knowledge without jeopardizing the security of the code. The Rivest-Shamir-Adleman code is based on the relative ease of determining that two large numbers are prime and then multiplying them, compared with the great practical difficulty of factoring their product without prior knowledge of how it was constructed. If the 200-digit product of two 100-digit primes were made pub-



PRIME-NUMBER SIEVE, attributed to the ancient Greek scholar Eratosthenes, was one of the first methods invented for distinguishing primes from composites among the numbers up to some predetermined limit. The sieve is represented in the illustration by an inclined plane in which holes have been made; the numbers to be tested for primality are represented by balls that roll down grooves in the plane. The holes are made according to a fixed procedure. First, holes in the second row are made at every second groove except the groove designated 2. Thus all the even-numbered balls except the ball in groove 2 fall through the holes. Next the lowest-numbered groove without a hole is found, namely the third groove. Holes are then made in the third row at every third groove except the groove designated 3. The procedure is continued by making holes in every fifth groove in the fifth row, every seventh groove in the seventh row and so on, stopping after the row whose number is less than or equal to the square root of the largest number to be tested. The balls that do not fall through a hole correspond to prime numbers. For example, all 25 primes smaller than 100 can be determined by collecting all the balls from 2 to 100 that roll past the seventh row of holes. (There are no primes greater than 7 that are less than or equal to the square root of 100.)

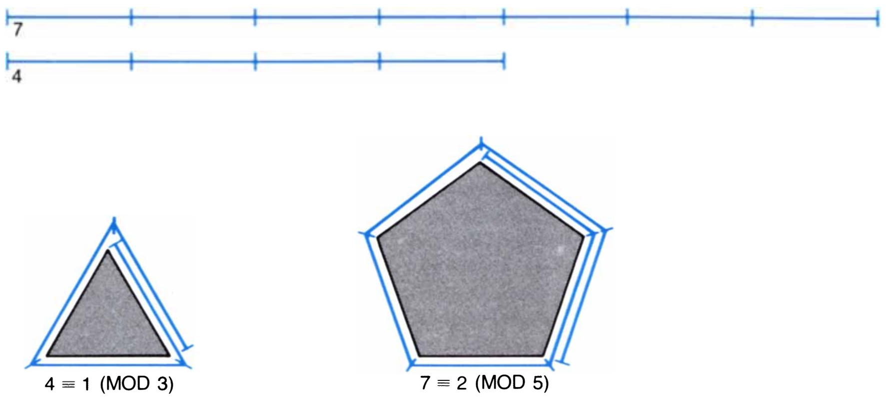
lic, anyone could encode a message by employing the 200-digit number. Only knowledge of the two prime factors, however, would make it possible to decode the message. There are public-key cryptographic systems that do not depend on factoring, but the security of the Rivest-Shamir-Adleman system rests on the intractability of the factoring problem, and its operation rests on the assumption that the 100-digit factors of the key number are indeed prime. Efficient primality tests that do not depend on factoring are therefore of great value to the cryptographic system [see "The Mathematics of Public-Key Cryptography," by Martin E. Hellman; SCIENTIFIC AMERICAN, August, 1979].

All known methods of testing primality that do not depend on factoring trace their lineage to a theorem first stated by Pierre de Fermat in a letter to his friend Bernard Frénicle de Bessy on October 18, 1640. The theorem, usually called Fermat's little theorem, states that if n is a prime number and b is any whole number, then $b^n - b$ is a multiple of n. For example, if n is equal to 7 and b is equal to 2, the theorem correctly states that $2^7 - 2$, or 126, is a multiple of 7.

For primality testing the importance of the theorem is the logically equivalent statement that if $b^n - b$ is not a multiple of n, then n is a composite number. When n is equal to 4 and b is equal to 3, the expression $3^4 - 3$ is equal to 78, which leaves a nonzero remainder (namely 2) when it is divided by 4. Hence the little theorem makes it possible to conclude, in a somewhat roundabout way, that 4 is not a prime.

Although the little theorem is a fundamental and powerful result, it has several elementary proofs, one of which I shall give below. The theorem makes it possible to state properties of numbers that are so large they cannot even be written in decimal form. From the fact that $2^{44,497} - 1$ is prime, for example, the theorem states that the number 3 raised to the power $2^{44,497} - 1$, minus 3, is evenly divisible by $2^{44,497} - 1$. The result of the exponentiation is a number so unimaginably huge that it could never be written in decimal form; furthermore, the process of division that would give the quotient explicitly could not possibly be done by any physically conceivable computer.

To get to such distant outposts of the number system one can use the arithmetic wheel, invented by Carl Friedrich Gauss. He formulated modular arithmetic, in which the absolute size of a number is irrelevant and all that matters is the size of the last turn of the arithmetic wheel employed to reach the number. The number n is expressed as the remainder after n is divided by some number m called its modulus; the remainder is written n modulo m, or n (mod m). The number m plays the role of the size of the wheel, the number n represents the absolute size of the number and the remainder n (mod m) represents the size of the last partial turn of the wheel needed to reach n.



MODULAR ARITHMETIC is a system of calculation with important applications in primality testing. In modular arithmetic the only thing that matters about any number *n* is the remainder when *n* is divided by some modulus *m*. The absolute size of the number *n* is disregarded. The most familiar example of modular arithmetic is the common system of telling time, in which the hours are designated by their values modulo 12. The triple-bar sign is read "is congruent to"; the numbers on each side of the sign have the same remainder when they are divided by the modulus. For example, the expression $4 \equiv 1$ (mod 3) means that 4 and 1 leave the same remainder when they are divided by 3, namely 1. The remainder is often called the residue.

In modular arithmetic many of the laws of ordinary arithmetic have close analogues. In particular it is possible to add and multiply in modular arithmetic as long as the results are expressed as congruences; all numbers that leave the same remainder with respect to a given modulus are said to be congruent with respect to that modulus. The remainder after division of a number by the modulus is often called the residue of the number with respect to the modulus.

In ordinary arithmetic 6 plus 7 is equal to 13, a result that is readily reproduced in arithmetic with a modulus of, say, 5. It turns out that 6 (mod 5) + 7 (mod 5) is congruent to 1 + 2, or in other words 3, and that 13 (mod 5) is also congruent to 3. Similarly, 4×5 is equal to 20, whereas in arithmetic modulo 3 the multiplication is done as 4 (mod 3) $\times$ 5 (mod 3), which is congruent to 1×2. The product is therefore 2, and 20 (mod 3) is also congruent to 2.

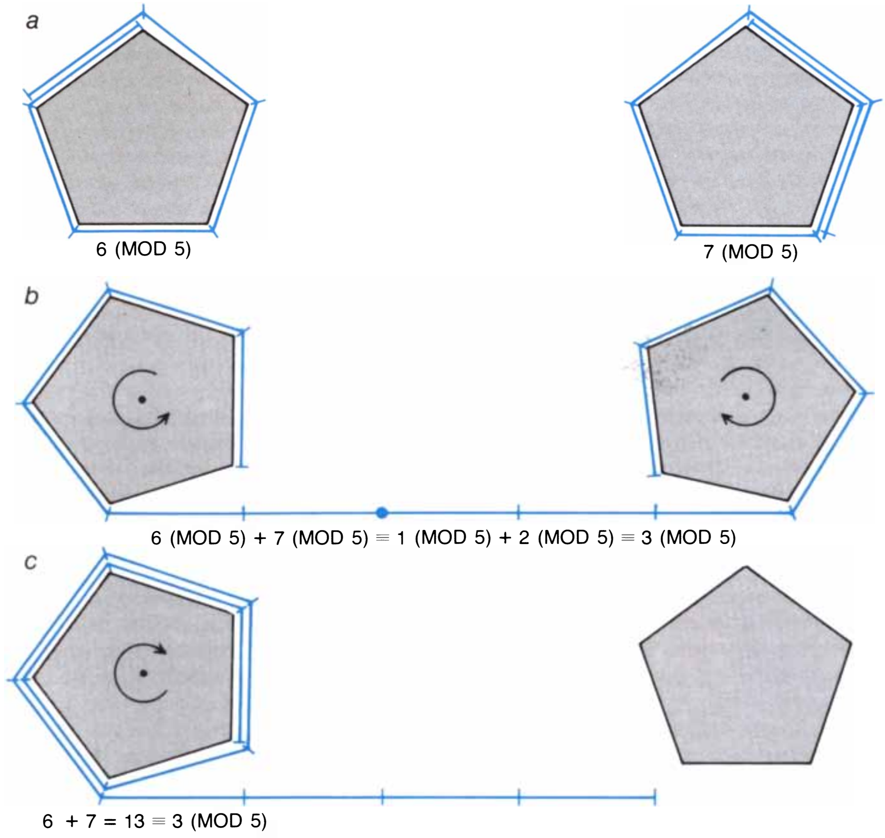
In Gauss's notation Fermat's little theorem states that if n is prime, then $b^n - b$ is congruent to 0 (mod n), or in other words $b^n - b$ is a multiple of n. The advantage of Gauss's notation is that the rules of modular arithmetic make it possible to calculate the value of $b^n - b$ modulo n without having to divide $b^n - b$ by n. For a number such as $2^7 - 2$ the advantages of Gauss's system do not seem to be significant because direct division is easy. To find the remainder when a number such as $3^{1,037} - 3$ is divided by 1,037, however, modular arithmetic becomes almost indispensable.

The essence of the problem is to find the value of $3^{1,037}$ (mod 1,037). In modular arithmetic it is not necessary to calculate the value of the enormous number $3^{1,037}$. All one need do is to repeatedly apply the fact that in modular arithmetic the residue of the square of a number is congruent to the square of the residue of the number.

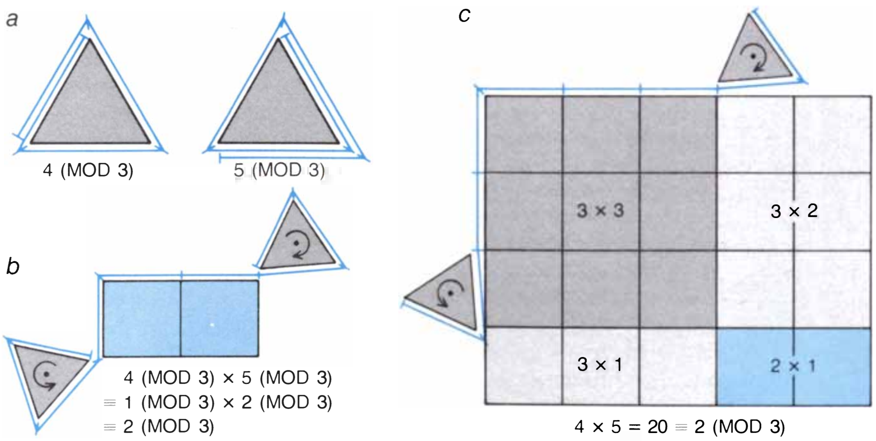
For example, once 3^8 (mod 1,037) is calculated, 3^{16} (mod 1,037) can be obtained by squaring the residue of 3^8 and finding the residue of this number modulo 1,037. In this way one can find the residues modulo 1,037 of 3, 3^2, 3^4, 3^8 and so on up to $3^{1,024}$. The number $3^{1,037}$ is equal to $3^{(1,024+8+4+1)}$, which in turn is equal to $3^{1,024} \times 3^8 \times 3^4 \times 3$ by the law of exponents; hence $3^{1,037}$ (mod 1,037) is congruent to $3^{1,024}$ (mod 1,037) $\times$ 3^8 (mod 1,037) $\times$ 3^4 (mod 1,037) $\times$ 3 (mod 1,037). When all the calculations are done, it is found that $3^{1,037}$ is congruent to 845 (mod 1,037), and so $3^{1,037} - 3$ is congruent to 842 (mod 1,037) [*see illustration on page 141*]. On the basis of Fermat's little theorem, therefore, 1,037 must be composite, since the remainder on dividing $3^{1,037} - 3$ by 1,037 does not equal zero. The procedure gives scarcely any clue that might be employed to find the factors of 1,037.

It is amusing to carry out the procedure with a programmable calculator. To avoid round-off errors the value of n should be limited to numbers with at most half of the number of digits displayed by the calculator. With a large computer the calculation can be done rapidly even if the input number has thousands of digits. Thus enormous numbers can often be identified by the Fermat test as being composite.

The proof of Fermat's little theorem follows from a simple consequence of



ADDITION IN MODULAR ARITHMETIC is carried out much as it is in ordinary arithmetic. The residue of each number with respect to the given modulus is determined and the residues are added. If the sum is greater than the modulus, the residue of the sum is found. In the example shown here the total length of two strings, one of length 6 and the other of length 7, is found modulo 5. In arithmetic modulo 5 the number of full turns a string takes around a pentagon is disregarded and only the length of the string that remains after the last full turn is considered relevant. Thus to modulo 5, 6 is congruent to 1 and 7 is congruent to 2 (*a*). When the residues of string are unwound and spliced, the total length of the two residues is 3 (*b*). When all the string is wrapped around one pentagon, the length of string that remains after all the full turns are taken is 3, and so the ordinary sum of 6 and 7 is congruent to 3 modulo 5 (*c*). In general the sum of the residues of two numbers is congruent to the residue of their ordinary sum.



MULTIPLICATION IN MODULAR ARITHMETIC is also done in a way similar to its analogue in ordinary arithmetic. In the example given 4 and 5 are multiplied modulo 3; they are represented as strings wrapped around a triangle. The residue of each number is the length of the string that remains after all full turns of the string around the triangle have been taken (*a*). The residue of 4 modulo 3 is 1 and the residue of 5 modulo 3 is 2. The product of the two residues is the area of the rectangle having sides equal to the length of each residue; in other words, 1 times 2 equals 2 (*b*). The product of 4 and 5, on the other hand, is the area of the rectangle having sides of length 4 and 5. The residue of the product (*c*) is obtained by disregarding the area of any smaller rectangle whose sides are equal to the length of string required for a whole number of turns around the triangle (*gray regions*). The area of the remaining rectangle (*colored region*) is the residue of the product of 4 and 5 modulo 3. Thus the general rule is that the product of the residues of two numbers is congruent to the residue of their ordinary product.

the fundamental theorem of arithmetic: If a prime number evenly divides the product of several numbers, then it evenly divides at least one of the numbers. For example, 4×9 or 36, is evenly divisible by the prime number 3, and of course one of the factors (namely 9) is also evenly divisible by 3. The statement is not true for a composite number: 4×9 is evenly divisible by 6, but neither 4 nor 9 is evenly divisible by 6.

To prove Fermat's result that $b^n - b$ is a multiple of n when n is prime, note that $b^n - b$ is equal to $b \times (b^{n-1} - 1)$. Hence if b itself is a multiple of n, so is $b^n - b$. The theorem thus remains to be proved only for the case in which b is not a multiple of n; the proof proceeds on this assumption.

The basic idea is that if the numbers b, $2b$, $3b$ and so on up to $(n - 1)b$ are multiplied together, their product can be rearranged as $b^{n-1}(n - 1)!$. On the other hand, it follows from the fundamental theorem of arithmetic that the residues modulo n of b, $2b$, $3b$ and so on up to $(n - 1)b$ are the numbers 1, 2, 3 and so on up to $n - 1$, possibly in some mixed-up order. Some elementary algebra then allows the conclusion that $(b^{n-1} - 1)(n - 1)!$ is a multiple of n. Because the prime number n does not evenly divide any of the numbers from 1 to $n - 1$, whereas n does evenly divide the product $(b^{n-1} - 1)(n - 1)!$, another application of the fundamental theorem of arithmetic implies that n evenly divides $b^{n-1} - 1$. Since $b^{n-1} - 1$ is a factor of $b^n - b$, the theorem follows.

It might appear that Fermat's little theorem completely solves the problem of primality testing, in that it seems to provide a quick way of distinguishing a prime number from a composite one. Unfortunately there is a logical flaw in this conclusion. If for some number b the number $b^n - b$ gives a nonzero remainder when it is divided by n, then n is certainly composite. Suppose, however, $b^n - b$ is a multiple of n. Does it follow that n must be prime?

Several examples suggest the answer is yes: $2^2 - 2$ is a multiple of 2, $2^3 - 2$ is a multiple of 3 and $2^5 - 2$ is a multiple of 5, and the numbers 2, 3 and 5 are all primes. Some 2,500 years ago Chinese mathematicians discovered the pattern and asserted that if $2^n - 2$ is a multiple of n, then n must be prime. Gottfried Wilhelm Leibniz, who made a study of the binary patterns in the *I Ching*, believed the result as well. In 1819, however, the French mathematician Pierre Frédéric Sarrus pointed out that $2^{341} - 2$ is a multiple of 341, even though 341 is a composite number, the product of 11 and 31. Since Sarrus's work many other counterexamples involving many different values of the base b have been found: $3^{91} - 3$ is a multiple of the composite number 91 and $4^{15} - 4$ is a multiple of the composite number 15. All these statements can be verified with a small calculator by applying modular arithmetic in the way I have already described.

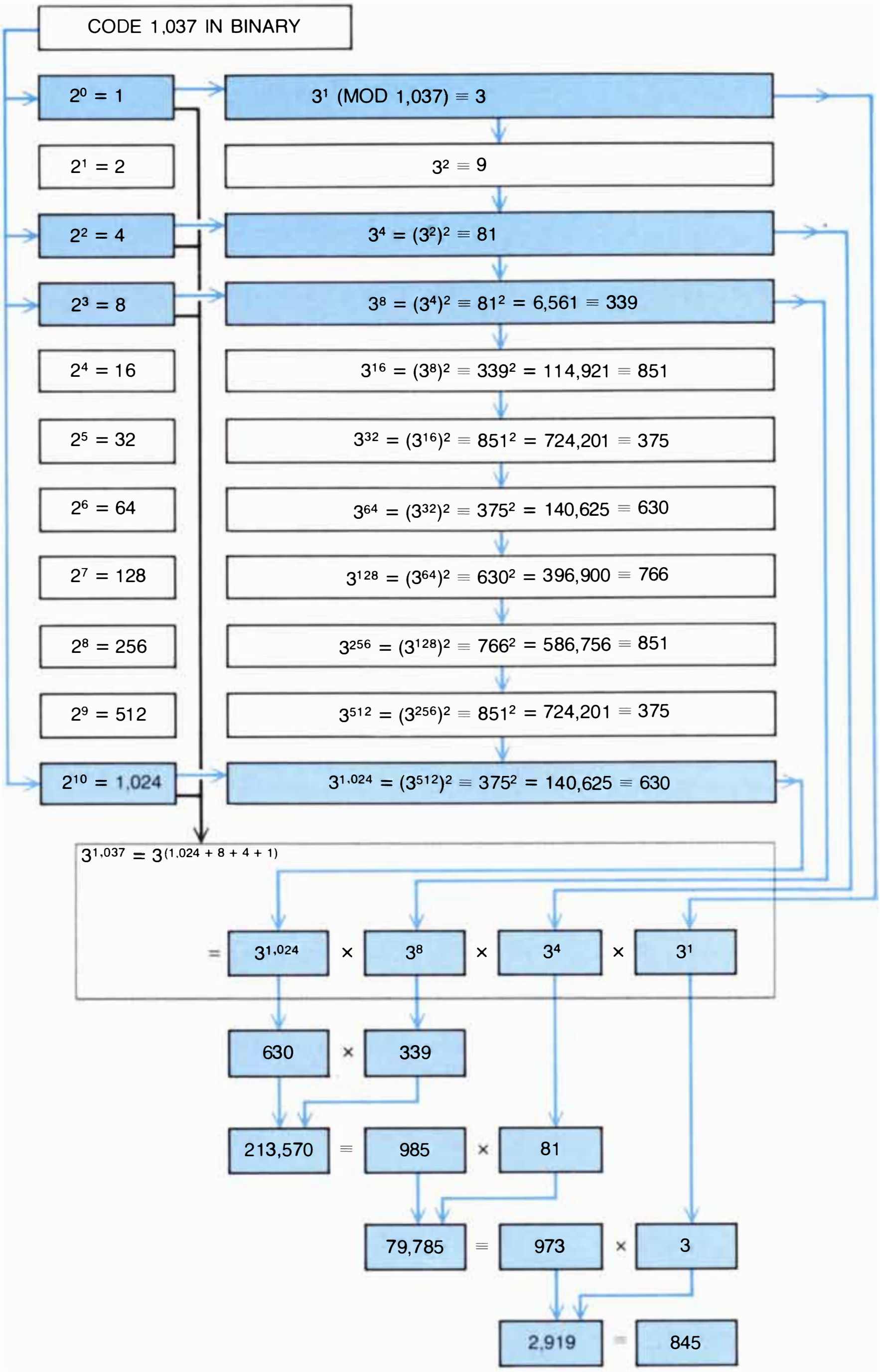
A number that fails to show up as a composite number by Fermat's test with a given value of b yet happens to be composite is called a pseudoprime to the base b. The number 341 is a pseudoprime to the base 2, whereas 91 is a pseudoprime to the base 3 and 15 is a pseudoprime to the base 4. It turns out that for every base b there are infinitely many pseudoprimes. There are even composite numbers, such as 561 (the product of 3, 11 and 17) and 1,729 (the product of 7, 13 and 19) that are pseudoprimes to every base b. Numbers of this kind are called Carmichael numbers, after the American mathematician R. D. Carmichael, who discovered their properties in 1909.

The existence of Carmichael numbers puts an end to any hope that the Fermat test, at least as it was originally formulated, can separate all the primes from the composites. Nevertheless, Carmichael numbers are exceedingly rare, and even the pseudoprimes to a single base b are rare when they are compared with the primes. Jan Bohman of the University of Lund has shown that there are exactly 882,206,716 primes smaller than 20 billion. John L. Selfridge of the journal *Mathematical Reviews* and Samuel S. Wagstaff, Jr., of the University of Georgia have calculated that there are only 19,865 pseudoprimes to the base 2 that are smaller than 20 billion. If the Fermat test were carried out to the base 2 for all the numbers smaller than 20 billion, the error rate would be only about one in a million.

The scarcity of pseudoprimes to the base 2 among all the numbers smaller than 20 billion suggests that any number that passes the Fermat test to base 2 is likely to be prime. Moreover, if the number is a composite that passes the Fermat test to base 2, it may not be able to pass the Fermat test to base 3. One would like to assert that by applying the Fermat test to base 3, one could significantly reduce the probability that a composite number that has passed the base-2 test is still posing as a prime. Because the tests may not be independent ones, however, the Fermat test to base 3 might not rule out many composites that had not already been eliminated by the base-2 test.

Recently a variation of the Fermat test that meets the requirement that tests to different bases be independent was developed by D. H. Lehmer of the University of California at Berkeley and independently by Robert M. Solovay of the California Institute of Technology and Volker Strassen of the Swiss Federal Institute of Technology. The test has the feature that if the test number n is composite, it will be recognized as composite for at least half of the values of the base b between 1 and n. Thus by randomly choosing, say, 100 different bases and applying the Lehmer-Solovay-Strassen test to each one, the probability that some random composite number n will pass all 100 tests is less than or equal to one in 2^{100}, or about one in 10^{30}.

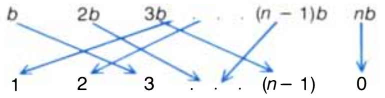
Solovay and Strassen said that their test constitutes a "Monte Carlo primality test." (A number of probabilistic methods in mathematics and physics have been named for the city noted for



APPLICATION OF MODULAR ARITHMETIC circumvents calculations that would be exceedingly time-consuming and prone to error if they were done in ordinary arithmetic. The flow chart demonstrates how the remainder can be found when the number $3^{1,037}$ is divided by 1,037, without ever calculating the value of $3^{1,037}$. The method depends on the fact that the residue of the square of a number is equal to the square of its residue to a given modulus. By repeatedly squaring the residue of a power of 3 and taking the residue of the result one can find in sequence the residues modulo 1,037 of 3, 3^2, 3^4, 3^8, 3^{16} and so on up to $3^{1,024}$. Because $3^{1,037}$ is equal to $3^{1,024} \times 3^8 \times 3^4 \times 3$, the remainder when $3^{1,037}$ is divided by 1,037 is equal to the residue of the product of the residues $3^{1,024}$ (mod 1,037) $\times$ 3^8 (mod 1,037) $\times$ 3^4 (mod 1,037) $\times$ 3 (mod 1,037). The entire procedure can be done with a programmable calculator.

CONSIDER THE NUMBERS b, $2b$, $3b$,..., $(n-1)b$, nb

FINDING THE RESIDUES OF THE NUMBERS MODULO n SETS UP A CORRESPONDENCE IN WHICH THE REMAINDERS ARE A PERMUTATION OF THE COEFFICIENTS OF b.



HENCE $b \times 2b \times \ldots \times (n-1)b \pmod{n} \equiv 1 \times 2 \times \ldots \times (n-1) \pmod{n}$.

THEREFORE $[b \times 2b \times \ldots \times (n-1)b] - [1 \times 2 \times \ldots \times (n-1)] \equiv 0 \pmod{n}$.

BUT $b \times 2b \times \ldots \times (n-1)b = b^{n-1}(n-1)!$ AND $1 \times 2 \times \ldots \times (n-1) = (n-1)!$.

HENCE $[b \times 2b \times \ldots \times (n-1)b] - [1 \times 2 \times \ldots \times (n-1)] =$

$[b^{n-1}(n-1)!] - [(n-1)!] = (b^{n-1} - 1)(n-1)! \equiv 0 \pmod{n}$.

THEREFORE $(b^{n-1} - 1)(n-1)!$ IS A MULTIPLE OF n, WHICH IS SUFFICIENT TO PROVE FERMAT'S THEOREM.

PROOF OF FERMAT'S "LITTLE THEOREM" follows from the application of the fundamental theorem of arithmetic and from the rules of multiplication in modular arithmetic. Fermat's little theorem states that if n is a prime number and b is any whole number, $b^n - b$ is a multiple of n. For the case in which b is a multiple of n, the conclusion of the theorem follows at once: because $b^n - b$ is equal to $b(b^{n-1} - 1)$, b is a factor of $b^n - b$ and so $b^n - b$ is a multiple of n. For the case in which b is not a multiple of n it is sufficient to show that $b^{n-1} - 1$ is a multiple of n. A corollary to the fundamental theorem of arithmetic states that if a prime number evenly divides the product of several numbers, it also evenly divides one of the numbers. Thus because n does not evenly divide any of the numbers from 1 to $n-1$, n does not evenly divide their product $(n-1)!$ either. Hence if it can be proved that $(b^{n-1} - 1)(n-1)!$ is evenly divisible by n, then it follows that $b^{n-1} - 1$ and $b^n - b$ are also evenly divisible by n. Consider the numbers b, $2b$, $3b$ and so on up to nb. No two of the numbers, say ib and jb, can give the same remainder when they are divided by n. If they could, then $ib - jb$, which is equal to $(i-j)b$, would be a multiple of n, because subtraction would cause the two remainders to cancel. Since b is not a multiple of n, the fundamental theorem of arithmetic implies that $i - j$ is a multiple of n. The number n, however, cannot evenly divide any numbers of the form $i - j$, where i and j are chosen from the sequence of numbers from 1 to n. Thus the supposition that ib and jb give the same remainder when they are divided by n leads to a contradiction. Because the remainder when n divides nb is 0 and because division by n only gives remainders from 0 to $n-1$, the numbers b, $2b$, ..., $(n-1)b$ must give all the remainders from 1 to $n-1$, in some order, when they are divided by n. The diagram shows that dividing the numbers b, $2b$, ..., $(n-1)b$ by n and then taking the remainder amounts to setting up a correspondence between the numbers b, $2b$, ..., $(n-1)b$ and the numbers 1, 2, ..., $(n-1)$ in some order. Since the residues of the numbers in each set are the same except for order, the residue of the product $b \times 2b \times \ldots \times (n-1)b$ is equal to the residue of the product $1 \times 2 \times \ldots \times (n-1)$. Subtracting one product from the other causes the residues to cancel, and so the difference of the two products is a multiple of n. The algebraic manipulations show that the difference of the two products is equal to $(b^{n-1} - 1)(n-1)!$, and so this expression is evenly divisible by n. Fermat's little theorem is thereby proved for all whole numbers b.

341 PSEUDOPRIME TO BASE 2

$2^{341} = 2^{256} \times 2^{64} \times 2^{16} \times 2^4 \times 2$

$\equiv 64 \times 16 \times 64 \times 16 \times 2 \pmod{341}$

$\equiv 2 \pmod{341}$

HENCE $2^{341} - 2 \equiv 0 \pmod{341}$

THEREFORE 341 PASSES THE FERMAT TEST TO BASE 2

BUT $341 = 11 \times 31$

561 PSEUDOPRIME TO ANY BASE

$2^{561} = 2^{512} \times 2^{32} \times 2^{16} \times 2$

$\equiv 103 \times 103 \times 460 \times 2 \pmod{561}$

$\equiv 2 \pmod{561}$

HENCE $2^{561} - 2 \equiv 0 \pmod{561}$

THEREFORE 561 PASSES THE FERMAT TEST TO BASE 2

BUT $561 = 3 \times 11 \times 17$

$3^{561} = 3^{512} \times 3^{32} \times 3^{16} \times 3$

$\equiv 273 \times 273 \times 69 \times 3 \pmod{561}$

$\equiv 3 \pmod{561}$

HENCE $3^{561} \times 3 \equiv 0 \pmod{561}$

THEREFORE 561 PASSES THE FERMAT TEST TO BASE 3

PSEUDOPRIME is a number that passes the test for primality derived from Fermat's little theorem for some base b but is nonetheless a composite number. Thus a pseudoprime to the base b is a composite number n that divides $b^n - b$ evenly. The French mathematician Pierre Frédéric Sarrus was the first to point out that 341, which is the product of 11 and 31, is a pseudoprime to the base 2. The verification that $2^{341} - 2$ is evenly divisible by 341 is done here in modular arithmetic in a way similar to the procedure in the illustration on the preceding page. Some numbers, called Carmichael numbers after the American mathematician R. D. Carmichael, are pseudoprimes to any base b. The number 561, which is the product of 3, 11 and 17, is the smallest Carmichael number; here it is shown to be a pseudoprime to the bases 2 and 3.

its games of chance.) In a practical sense the description seems accurate; it would appear, for example, that in the cryptographic application the operation of a code is not handicapped by a vanishingly small chance that the numbers on which it is based are not prime after all. It has also been argued, however, on what I regard as shaky philosophical grounds, that because every ordinary mathematical proof is subject to correction and human error, one ought to accept a strong probabilistic verification of primality as being a mathematical proof of primality.

There is indeed reason to believe the probability is considerably greater than one in 10^{30} that arguments accepted as mathematical proofs are in error. The history of mathematics bears witness to numerous examples of "proof" that later turned out to be misleading or erroneous. There is, however, a qualitative difference between probabilistic verification and mathematical proof that is important to mathematicians. A proof is a deductive argument, in which each step follows logically from the preceding steps. The proof carries such weight not only because the conclusion can be seen to be valid but also because a valid conclusion must follow from the force of the argument. What the idea of a Monte Carlo primality test does suggest, I think, is that the concept of proof and the concept of certainty are quite different from each other.

In 1876 the French mathematician Édouard A. Lucas gave an ironclad primality test for any number n. Suppose there is a number b for which b^{n-1} is congruent to 1 modulo n but for which $b^{(n-1)/p}$ is not congruent to 1 modulo n for each prime factor p of $n-1$. Then Lucas proved that n must be prime.

For example, suppose the number n to be tested is 257; then $n-1$ is equal to 256, or 2^8, so that every prime factor p of $n-1$ is equal to 2. In order to prove that n is prime one must find a number b such that b^{256} is congruent to 1 modulo 257 but $b^{256/2}$ is not congruent to 1 modulo 257. Although there is no indication given by the Lucas test of how to find the special number b, many such numbers satisfy the conditions of the theorem for any prime number n; a random search will almost always be successful. When b is equal to 3, for example, 3^{256} is congruent to 1 modulo 257, but $3^{256/2}$ is congruent to 256 modulo 257. Hence 257 is prime. Although the Lucas test too is a Monte Carlo test, in the sense that the number b must be selected at random, it delivers a rigorous proof of primality once the number b is found.

There is one aspect of the Lucas test that limits it to numbers having a special form. Unless every prime factor p of the number $n-1$ can be found, the test cannot be applied. Of course, if n is suspected to be prime, it is an odd number, and

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CAVALIER · CELEBRITY · CHEVETTE · CAMARO · CITATION · MALIBU · MONTE CARLO · CAPRICE · CORVETTE so $n-1$ is divisible by 2. Such a head start is seldom enough; the Lucas test is not generally feasible unless $n-1$ factors easily, as it did in my example.

If all the prime factors of $n+1$ can be found more readily than those of $n-1$, another test (also first proposed by Lucas) can determine the primality of the number n. Lehmer improved on the test in 1930, and for the numbers to which it can be applied the Lucas-Lehmer test can be run extremely fast on a large computer. The test has demonstrated the primality of the largest primes known, numbers of the form 2^p-1, where p itself is a prime number. Such numbers are called Mersenne numbers, after the 17th-century French mathematician Marin Mersenne, who once gave a list of prime numbers p for which he believed 2^p-1 is prime. It is evident that if n is a Mersenne number, all the prime factors of $n+1$ are known at once: they are all equal to 2.

In 1975 John Brillhart of the University of Arizona, Lehmer and Selfridge showed how to construct a primality test for a number n if only some of the prime factors of $n-1$ or $n+1$ are known. Hugh C. Williams of the University of Manitoba has raised this kind of testing to a fine art: partial factorizations of n^2+1, n^2-n+1 or n^2+n+1 are now sufficient for testing the primality of n. If none of the numbers factors easily, however, the tests bog down. Although many 100-digit numbers can be tested by such methods, it has been estimated that the testing of certain stubborn 100-digit primes would have required a century of computer time. Thus what has been needed is a test for primality that does not depend on the special form of the number being tested.

In 1980 Adleman and Robert S. Rumely of the University of Georgia developed a test that has radically altered the efficiency of testing the primality of large numbers having no special form. The test as it was originally formulated was probably capable of testing the primality of any number having from 50 to 100 digits in four to 12 hours with a large computer. Henri Cohen of the University of Bordeaux and Hendrik W. Lenstra, Jr., of the University of Amsterdam have since improved the test in several significant ways so that it can now run about 1,000 times faster: a 100-digit number can be tested in about 40 seconds with the Control Data Corporation-Cyber 170-750 computer.

How does the Adleman-Rumely test achieve such efficiency? Its details require a technical understanding of algebraic number theory, but in its essence the test is quite similar to the one devised by Fermat. Two auxiliary numbers, called the initial number I and the Euclidean number E, are constructed. The number I is a product of several primes, such as $2 \times 3 \times 5 \times 7$, or 210. The number E is called the Euclidean number because its definition is reminiscent of Euclid's proof that there are infinitely many primes. E is the product of all the primes p, q, r and so on, such that the numbers $p-1$, $q-1$, $r-1$ and so on are all factors of I. The number 70, for example, is a factor of 210, and because 70 is one less than the prime number 71, 71 is defined as a factor of the Euclidean number E. The factors of 210 that are exactly one less than a prime number are 1, 2, 6, 10, 30, 42, 70 and 210 itself. Hence E is the product of the

THE MERSENNE PRIMES TO $2^{62,982}$

VALUE OF p FOR WHICH 2^p-1 IS PRIME	2^p-1	WHEN PROVED PRIME	BY WHOM	MACHINE USED
2	3			
3	7	ANTIQUITY	MENTIONED IN EUCLID'S ELEMENTS	
5	31			
7	127			
13	8,191	1461	MENTIONED IN CODEX LAT. MONAC. 14908	
17	131,071	1588	PIETRO ANTONIO CATALDI	
19	524,287			
31	2,147,483,647	1772	LEONHARD EULER	
61	19 DIGITS	1883	I. M. PERVOUCHINE	
89	27 DIGITS	1911	R. E. POWERS	
107	33 DIGITS	1914	R. E. POWERS, E. FAUQUEMBERGE	
127	39 DIGITS	1876 – 1914	ÉDOUARD LUCAS, E. FAUQUEMBERGE	
521	157 DIGITS			
607	183 DIGITS			
1,279	386 DIGITS	1952	RAPHAEL M. ROBINSON	SWAC
2,203	664 DIGITS			
2,281	687 DIGITS			
3,217	969 DIGITS	1957	HANS RIESEL	BESK
4,253	1,281 DIGITS	1961	ALEXANDER HURWITZ	IBM-7090
4,423	1,332 DIGITS			
9,689	2,917 DIGITS			
9,941	2,993 DIGITS	1963	DONALD B. GILLIES	ILLIAC-II
11,213	3,376 DIGITS			
19,937	6,002 DIGITS	1971	BRYANT TUCKERMAN	IBM 360/91
21,701	6,533 DIGITS	1978	LAURA NICKEL, CURT NOLL	CDC-CYBER-174
23,209	6,987 DIGITS	1979	CURT NOLL	CDC-CYBER-174
44,497	13,395 DIGITS	1979	HARRY L. NELSON, DAVID SLOWINSKI	CRAY-1

MERSENNE PRIME is a prime number that is one less than a power of 2; the numbers of this form are named for the French mathematician Marin Mersenne. Such primes have been of interest since antiquity because, as was shown by Euclid, if the number 2^p-1 is prime, the number $2^{p-1}(2^p-1)$ is perfect, that is, equal to the sum of all its factors except itself. If 2^p-1 is prime, then p too is prime, but the converse does not necessarily hold. It is not known whether there are infinitely many Mersenne primes, nor is it known whether there are infinitely many Mersenne composites, but both statements are probably true. In recent years the growth of the table of known Mersenne primes has paralleled the growth of computing power. According to David Slowinski of the Lawrence Livermore Laboratory, showing that $2^{8,191}-1$ is not a prime took 100 hours with the ILLIAC-I computer, 5.2 hours with the IBM System 7090, some 49 minutes with the ILLIAC-II, 3.1 minutes with the IBM System 360/91 and 10 seconds with the CRAY-1. Slowinski and Harry L. Nelson, also of Lawrence Livermore, have examined the Mersenne numbers for all values of p up to 50,000 without identifying any primes larger than $2^{44,497}-1$. Recently Guy M. Haworth, Steven M. Holmes, David J. Hunt, Thomas W. Lake and Stewart F. Reddaway of International Computing Limited have been continuing the search with the help of the ICL-DAP, a supercomputer having 4,096 processors that operate in parallel. They have now searched for Mersenne primes for values of p up to 62,982 without finding any new Mersenne primes.

prime numbers 2, 3, 7, 11, 31, 43, 71 and 211, or 9,225,988,926. The number E must be constructed so that it is larger than the square root of the number n being tested for primality; in my example, with the initial number 210, the Adleman-Rumely method would work as long as n is no larger than about 10^{19}. The running time for the computer is proportional to a power of the number I, and so I should also be chosen to be as small as possible.

There is a kind of dynamic tension between the numbers E and I. For the test to be valid E must be large; for the test to be fast I must be small. Moreover, since E depends on I, the auxiliary numbers cannot be chosen independently of each other. The number 210 is a good example of a choice for I because it is a relatively small number with many factors that are one less than a prime. To prove that the Adleman-Rumely test is always fast it was necessary to verify that suitable numbers E and I can always be found and to give an estimate of their size.

By coincidence, work on the question had already been done. In 1955 Karl Prachar of the Agricultural University of Vienna showed that there are infinitely many integers having a large number of factors that are one less than a prime. To apply Prachar's result to the original Adleman-Rumely test it was necessary to show that the numbers I could be constructed so that they are "square-free," that is, not divisible by any square of an integer larger than 1. Cohen and Lenstra have recently shown that in their variation of the test the square-free condition can be dropped. It was also possible to strengthen Prachar's result by employing later findings made by Patrick X. Gallagher of Columbia University and Enrico Bombieri of the Institute for Advanced Study. Andrew M. Odlyzko of Bell Laboratories and I analyzed the construction of the numbers that can appear as I in the new primality test.

After the numbers I and E have been constructed certain tests analogous to the Fermat test are done for each pair of primes p and q in which p, the first member of the pair, is a factor of E and q, the second member of the pair, is a factor of $p - 1$. The test is not carried out for whole numbers but rather for numbers called algebraic integers that correspond to p and q. An algebraic integer is a complex number that is the root of a polynomial whose coefficients are integers and whose leading coefficient is 1. For example, $\sqrt{2}$, i (the imaginary square root of -1) and $(-1 + i\sqrt{3})/2$ are all algebraic integers because they are roots of the algebraic equations $x^2 - 2 = 0$, $x^2 + 1 = 0$ and $x^3 - 1 = 0$.

If n, the number being tested for primality, fails the test corresponding to one of the pairs of primes p and q, then n is recognized to be composite. If n passes all the tests, it is still not certain to be prime, but the number of possible factors remaining to be checked is small. Adleman and Rumely have shown that any composite number n passing all tests of the Fermat type must have prime factors in a set with exactly I elements. Lenstra has shown that the numbers in the set are equal to the residues of the powers n, n^2, n^3 and so on up to n^I, modulo E. By trial division, if any of the numbers in the set other than 1 or n divides n without remainder, n is composite; otherwise n must be prime. Although the last step makes the Adleman-Rumely method appear to be a factoring method, I must stress that the conclusion of the last step is valid only if n has passed all previous tests of the Fermat type. Most and perhaps all composite numbers will fail at least one of the Fermat-type tests and so need not have a factor that can be found by the trial division of the last step.

The speed and completely general applicability of the new primality tests have opened the way to the theoretical investigation of numbers previously inaccessible even to the fastest computers. Suppose, however, arbitrary numbers

	SIZE OF NUMBER				
PRIMALITY TEST	20 DIGITS	50 DIGITS	100 DIGITS	200 DIGITS	1,000 DIGITS
TRIAL DIVISION	2 HOURS	10^{11} YEARS	10^{36} YEARS	10^{86} YEARS	10^{486} YEARS
LUCAS, BRILLHART-LEHMER-SELFRIDGE, WILLIAMS	5 SECONDS	10 HOURS	100 YEARS	10^{9} YEARS	10^{44} YEARS
ADLEMAN-RUMELY, COHEN-LENSTRA	10 SECONDS	15 SECONDS	40 SECONDS	10 MINUTES	1 WEEK

TIME REQUIRED to test an arbitrary number for primality varies widely according to the kind of primality test. Here it is assumed that the tests are run with a fast computer; in particular, for the method of trial division it is assumed that the computer does a million divisions per second regardless of the size of the number being tested. The running times given for the family of tests similar to the one invented by the French mathematician Édouard A. Lucas represent worst cases; prime numbers of special form can often be tested much faster. Most of the times listed are estimates, but entries shaded in color reflect experience with a computer. In practice all three kinds of test can be combined into one test that runs slightly faster than the third test.

having many more than 100 digits are subjected to the tests. How quickly can one expect the tests to deliver primality judgments for such numbers? This question and similar ones have become theoretically important for a branch of computer science called complexity theory. According to a currently accepted definition in complexity theory, a primality test is computationally slow unless it can be carried out in what is called polynomial time. That is, the test is regarded as being slow unless the time it takes to test a number n is less than a fixed power k of the number of digits in n. I shall designate the number of digits in n by the symbol $d(n)$; notice that $d(n)$ itself is a number, and so one can write the number of digits in $d(n)$ as $d(d(n))$.

It turns out that according to the definition provided by complexity theory, the Adleman-Rumely and Cohen-Lenstra tests are computationally slow. Their running time is bounded by $d(n)$ raised to the power $d(d(d(n)))$ times some constant c. The expression $d(d(d(n)))$ is the number of digits in the number of digits in the number of digits in the number n; no matter what the constant c is, the product of c and the expression will eventually exceed the constant k and become indefinitely large as n grows, and so the bound on the running time is not a polynomial one.

Nevertheless, for relatively "small" numbers the criterion provided by complexity theory can be misleading because the expression $d(d(d(n)))$ drifts toward infinity at an extremely leisurely rate. For example, even for a number n as large as $10^{1,000}$, $d(d(d(n)))$ is only equal to 1. The first number n for which the expression is equal to 2 is $10^{999,999,999}$. In other words, for all numbers less than $10^{999,999,999}$ the running time for the new primality tests is bounded by the power c of $d(n)$. Thus although the new tests do not run in polynomial time, they "nearly" do.

Now that primality testing can be done quickly for moderately large numbers attention may shift to the companion problem of factoring. Progress in factoring would of course have immediate implications for cryptographic systems based on factoring. The developments in primality testing have no direct bearing on the problem of factoring; on the other hand, no one has ever proved that factoring is intractable. There is no guarantee that someone will not invent a revolutionary method of factoring tomorrow. Therefore a decision on the long-term security of the public-key systems that are based on the difficulty of factoring calls for a subjective judgment of whether or not there will be any major advances in factoring. The recent developments in primality testing serve to emphasize the potential vulnerability of any such code to a theoretical breakthrough.

The Lamps of Cosa

The evolution of oil lamps, the chief indoor light of Classical civilization, is traced at one Italian site for seven centuries. These humble artifacts are key clues to the culture of the time

by Cleo Rickman Fitch

Man's use of artificial illumination other than firelight can be traced back to Paleolithic times; an example is the discovery of wick lamps at Lascaux Cave in France. Not until advances in agriculture made available such products as sesame oil, flaxseed oil and olive oil, however, did oil lamps come into general service. By Classical Greek times (beginning roughly in the fifth century B.C.) tens of thousands of these ingenious light sources, usually made of terra cotta, were being turned out by regional pottery manufacturers in Asia Minor, Greece, Sicily, parts of Italy and elsewhere in the ancient world. Around the Mediterranean well before the start of the Christian Era the practice of forming oil lamps individually on the potter's wheel had been supplanted by their mass production in molds.

The evolution of these humble objects in form, function and decoration is interesting both in its own right and for its usefulness in the study of ancient technology and society. How the lamps evolved in central Italy over a span of nearly 800 years, from Republican times to the fall of the Roman Empire, is now known as a result of an intensive archaeological campaign conducted at a town site on the Tyrrhenian coast. There, on a promontory across the bay from a coastal landmark, Mount Argentario, some 120 kilometers north of Rome, the *colonia* of Cosa was founded in 273 B.C. by the Romans and their allies of the Latin League after their victory a few years earlier over two Etruscan city-states, Vulci and Volsinii. Cosa was to be a frontier strongpoint, defending the conquered territory from other Etruscan antagonists farther to the north.

Although Cosa was settled by some 2,500 families, there was room for no more than 300 houses, in addition to the usual public buildings, inside the great stone walls that testified to the town's military purpose. The street grid consisted of rectangular blocks, with the main streets running from northwest to southeast. A public storehouse was built just inside the northwest gate. Other public buildings included the town's most important temple (dedicated to Jupiter, Juno and Minerva), a smaller temple (dedicated to Mater Matuta, goddess of the dawn), the forum (roughly in the center of town), an area of shops and a bath. Because the bedrock of Cosa is a porous limestone there were no town wells; the inhabitants depended on rainwater collected in large public cisterns and smaller individual cisterns under each residence.

The American Academy in Rome has conducted a campaign of excavations at Cosa since 1948, using the town site as a training ground for budding Classical archaeologists. A total of 14 seasons' work has now been accomplished, much of it under the direction of Frank E. Brown, formerly of Yale University and from 1965 to 1969 director of the academy. The excavations are also responsible for the recovery of the material under discussion here: the fragments of thousands of oil lamps and a few intact ones. Some of the lamps had been made locally or had been imported from southern Italy, Sicily and North Africa. The majority, however, had been manufactured by potters in and around Rome.

When night fell in Cosa, as in other towns and villages of the time, the homes of the well-to-do were lighted by candelabras and by oil lamps made of bronze and even of precious metals, the altars of the temples glowed with votive lights and oil lamps shone in wineshops and taverns. There were lamps in ordinary homes too, but they were lighted only on special occasions. Like peasants everywhere, the householders wasted little oil, usually going to bed when it got dark and rising before dawn. Nevertheless, there were few households that did not have an earthenware lamp or two. Such pottery, however, is fragile, and so it is no surprise that most of the lamps found in Cosa were broken.

For all its simplicity the oil lamp was a remarkable invention. The first lamps were shallow fired-clay bowls, thrown on a potter's wheel or shaped by hand. The bowl was half filled with oil; the wick simply floated on the liquid. Then some imaginative potter pinched the edge of the bowl before the clay was fired, forming a small lip where one end of the wick could rest above the level of the oil. The next innovation was to turn the edge of the bowl inward, except for the pinched part, thereby reducing the risk of the oil's being spilled. At about this time it became customary to attach a handle to the side of the lamp opposite the lip. The trend continued until there was only a small opening in the top: the filling hole.

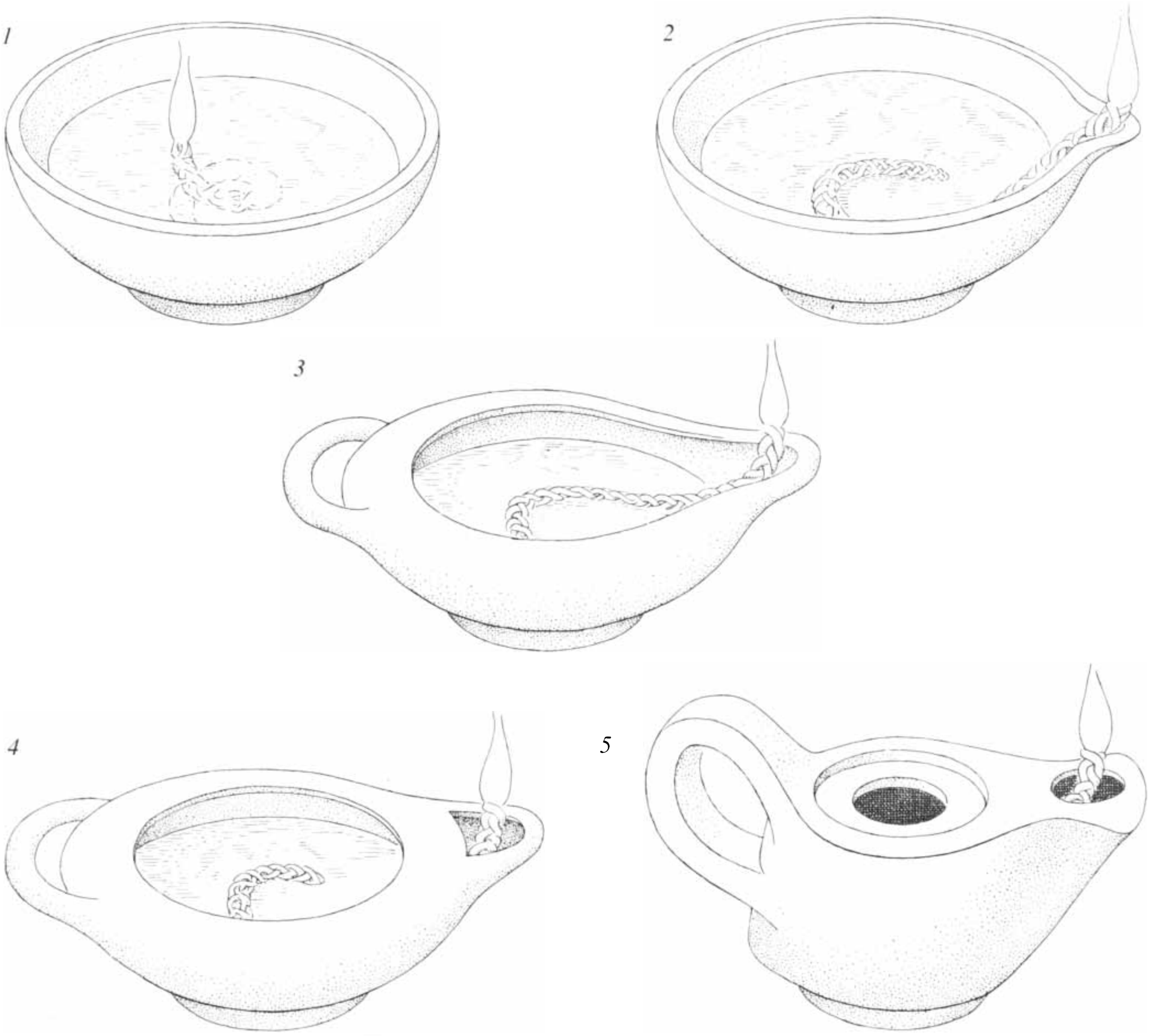
Next the lip disappeared and a hand-molded clay cone took its place. The potter attached the cone to one side of the lamp while it was still soft and then poked a hole through the cone, from its tip on down into the lamp's oil reservoir, thereby providing a nozzle for the wick. Later, in the third century B.C., potters in Asia Minor began to mass-produce lamps in two-part molds. Because certain steps in the molding process do not call for skilled labor the new manufacturing technique was soon adopted elsewhere. The process is as follows.

The potter first makes a patrix, a full-scale solid model of the lamp, carved from wood or stone or modeled in clay and fired to great hardness. Whatever decoration the lamps are to display appears on the patrix; so do marks indicating the position of the filling hole and wick hole. Using the model as his master, the potter then makes a matrix in two parts; one part reproduces in negative the upper half of the patrix and the other part reproduces in negative the lower half. The two-part matrix is made either of plaster or of hard-fired clay, and its interior relief duplicates in reverse the form and decoration of the original. The key to mass production is that the potter can make as many of these matrixes as he wants.

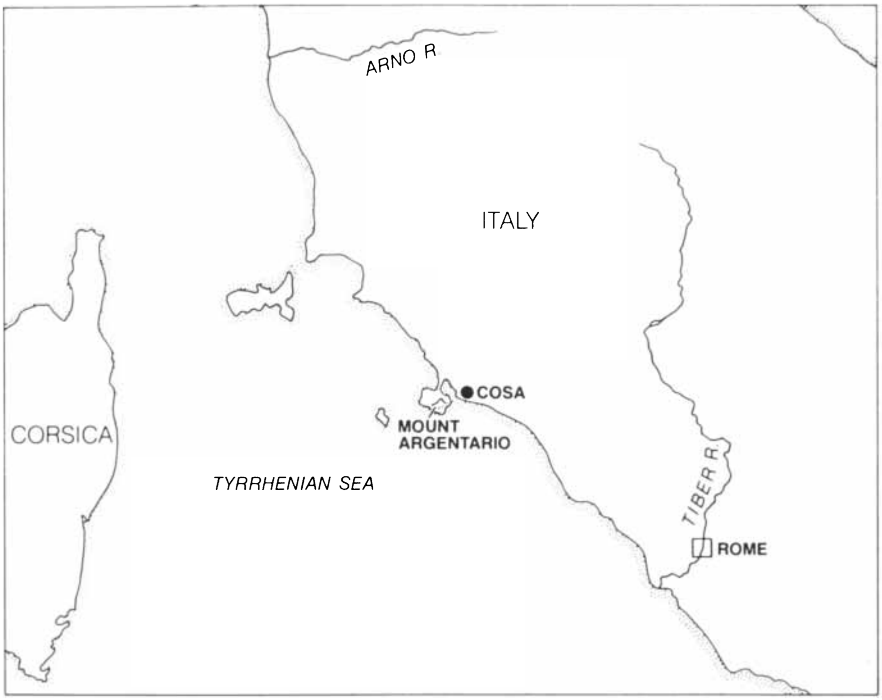
The next step in the process, which can be accomplished by unskilled labor, is to line the two halves of each matrix with a thin layer of soft clay and trim away any surplus. The two halves are set aside until the drying clay inside them is as hard as leather. The molded clay is then removed from each half and assembled, with a thin slurry of wet clay serving as a cement. The filling hole and wick hole of the assembled lamp are punched through at the points indicated and the lamp is set aside to harden before firing.

All the oil lamps and lamp fragments found at Cosa except one are terra cotta. The exception is a lamp made out of iron. All except one were either wheel-thrown or molded; the exception is a hand-formed lamp. The wheel-thrown lamps, as might be expected from the history of lamp evolution, characterized the early centuries of the town's occupation. Indeed, some of them were probably brought to the site by the first settlers. This conjecture is supported by the location of the site where they were found: a sacred pit under the floor of the central room of the main temple, the space sacred to Jupiter. In the customary Roman ceremony at the founding of a new town such a pit was prepared on the site of the temple-to-be and the blessing of Jupiter was invoked. The settlers then lined up and tossed various belongings into the pit as offerings to the god. The pit was filled, a temporary altar was raised over it and the slower work of constructing the temple itself was begun. Hence the lamps found in the pit can be dated to no later than the founding of Cosa in 273 B.C.

The three kinds of lamps from the pit make up a majority of the five kinds of wheel-thrown oil lamps found at Cosa. They are Type A, described as a "doughnut" lamp; Type B, a "truncated cone" lamp, and Type C, a "tubular" lamp. The fourth kind of wheel-thrown lamp found at Cosa—Type D, a "watch" lamp—first appears in later stratigraphic contexts (dated between 225 and 200



HYPOTHETICAL EVOLUTION of Mediterranean oil lamps begins (*1*) with a wick floating in an oil-filled saucer. Some unknown improviser then pinched one side of the saucer rim before firing it (*2*), providing a shelf for the wick. Further innovations (*3*) included an extension of the shelf, making the saucer more oval, the addition of a handle opposite the shelf and an inversion of the rim of the saucer to minimize oil spills. The next advance was similar to the addition of the handle; the pinched rim was bridged over to produce a nozzle (*4*) opposite the handle. Next a preformed nozzle took the place of the bridged pinch (*5*). This attached nozzle became bulkier, the lamp reservoir deeper, the top opening smaller and the handle vertical. In the third century B.C. potters in Asia Minor added lamps made in molds to their repertory of lamps thrown on the potter's wheel. This more economical practice soon caught on around the Mediterranean.



TOWN OF COSA, a frontier strongpoint, was established near a coastal landmark, Mount Argentario, in 273 B.C. after Rome and her allies conquered two local Etruscan city-states.

COSA TOWN WALL, roughly pentagonal, enclosed within its 1.5-kilometer circumference a total area of 13¼ hectares. The town depended on rainfall and on springs outside the wall for water. The dot in color designates the collapsed storeroom where most of the lamps were found.

B.C.). The fifth kind—Type E, a "cylindrical" lamp—first appears sometime between 120 and 70 B.C. The Type C lamp was a composite: the body was made in imitation of an earlier Greek style but the nozzle was Roman. Its shape was suitable for mounting on any convenient bracket or for resting on any flat surface. Its open top, however, was an invitation to oil-hungry mice, and insects attracted to its flame at night must have fallen into the oil reservoir.

After 70 B.C. Type C and Type D lamps are no longer found at Cosa; presumably the potters in the vicinity of Rome stopped making them. The other three wheel-thrown types, however, continued to be made even after molded lamps began to dominate the market. Indeed, one Type A lamp has been found at Cosa in a context that places it between A.D. 250 and the time of the town's abandonment in A.D. 500.

Cosa's nearly 800-year history was by no means uneventful. It includes several intervals when neither oil lamps from regional potteries in Italy nor imports from overseas reached the town. The three Punic wars were such intervals. The first of the wars (264–241 B.C.) began only a few years after the founding of Cosa, and in the second (218–201 B.C.) Hannibal's troops were on the march in central Italy. What might have been a century of peace between the Carthaginians' final defeat (149–146 B.C.) and the wars set off by the collapse of the Roman Triumvirate (49–31 B.C.) was for Cosa punctuated by a pirate raid that saw the town captured and sacked in about 70 B.C.

One Quintus Fulvius, a prosperous townsman, may have been forewarned. In any event he buried under the floor of his pantry 2,000 denarii, the latest of them minted in 72–71 B.C. Fulvius seems to have met his end in the raid, because his hoard remained undisturbed until American Academy workers discovered it a few seasons ago. With the triumph of Augustus in 31 B.C. peace returned to Rome, and a few years later Cosa was resettled. The town was to endure for another half millennium, gradually dwindling in population and importance until it was finally abandoned.

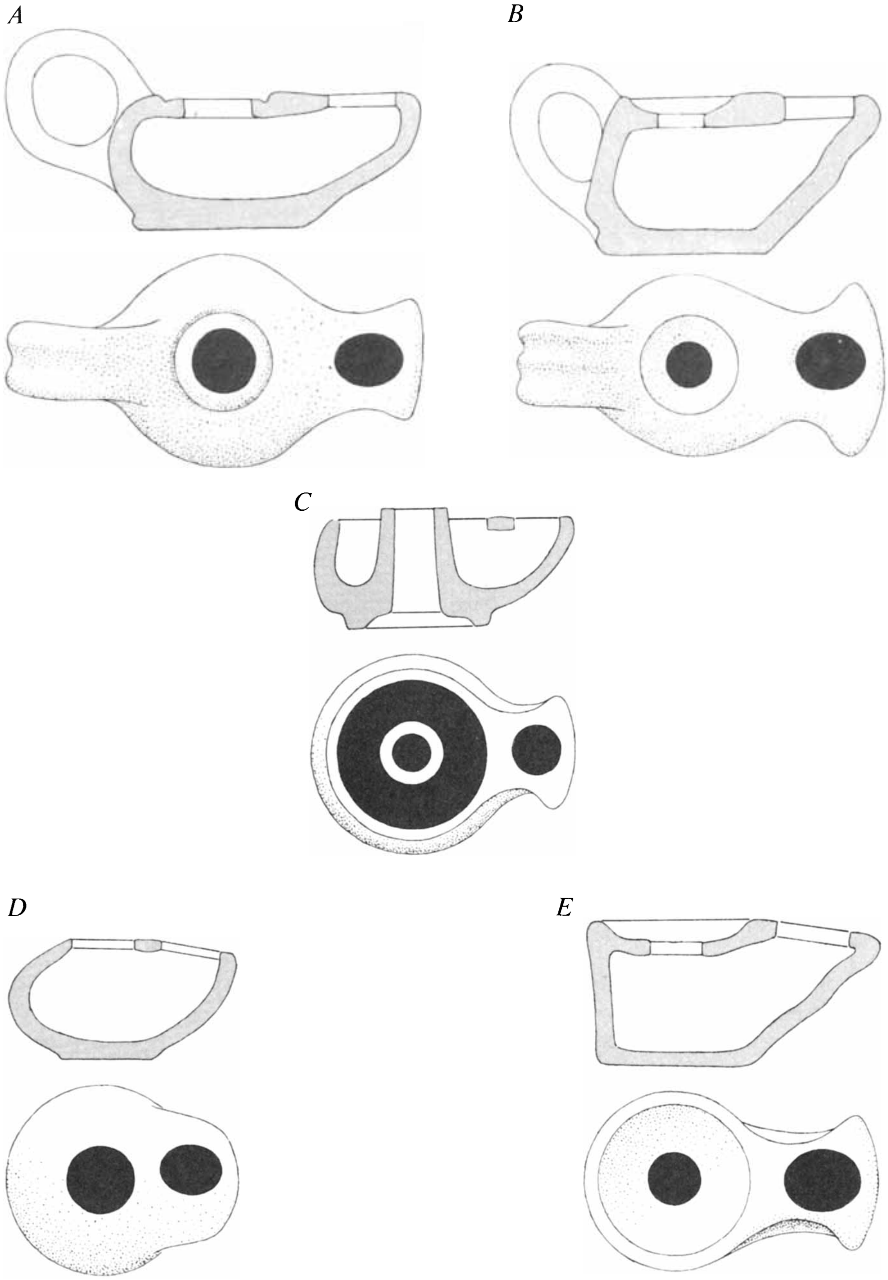
The first molded oil lamps did not reach Cosa until after 120 B.C., but between that date and the pirate raid the townsfolk acquired not only molded lamps of Roman manufacture but also molded imports from Sicily, Greece and Asia Minor. With the technique of mold manufacture came the practice of decorating the lamps with low reliefs. The themes of the decorations were drawn from various artistic representations of the period, including many of the figures of mythology. Quite apart from the decorations on the lamps manufactured abroad, the decorations applied by the

Roman potters began to reflect the artistic influence of the objects the victorious Romans had carried back as booty from the higher cultures of Egypt, Greece and Asia Minor.

Among the imports a number of lamps probably manufactured in Sicily were found in the fill around Cosa's main temple and are dated to between 120 and 70 B.C. They are known as delphiniform lamps because their shape is reminiscent of a dolphin. They have a hard, dark gray fabric and a black glaze. The relief decorations on their upper half feature looped vines with flowers or concentric rows of a single leaf and a lotus blossom alternating with a narrow bead-and-reel design. Although these lamps were imports, they must have been made for the Roman market; their nozzles are Roman in style.

One Greek lamp found at Cosa bears the name of a well-known Athenian potter: Aristuno. He and his workshop disappeared after the sack of Athens by the Roman general Sulla in 86 B.C. Perhaps the lamp was part of the loot of Athens, brought back by one of Sulla's soldiers, or perhaps it was carried to Cosa by a traveler who had gone to Athens before Sulla did. In any event its upper half is decorated with a delicate design of overlapping scales.

Of the molded Roman lamps at Cosa one of the earliest and finest is the "raised dots" lamp, so called because the decoration consists of concentric rows of tiny granulations all over the body of the lamp. Evidently the original patrix of this molded design was a metal lamp, perhaps made of bronze. Lamps that almost exactly parallel one of these Roman products have been found both at Carthage in North Africa and on the Greek island of Delos. The type was popular in central Italy until the time of Augustus. The original patrix must eventually have disappeared, because the quality of the lamps deteriorates. On the later lamps the dots get progressively larger and are found only on the top.



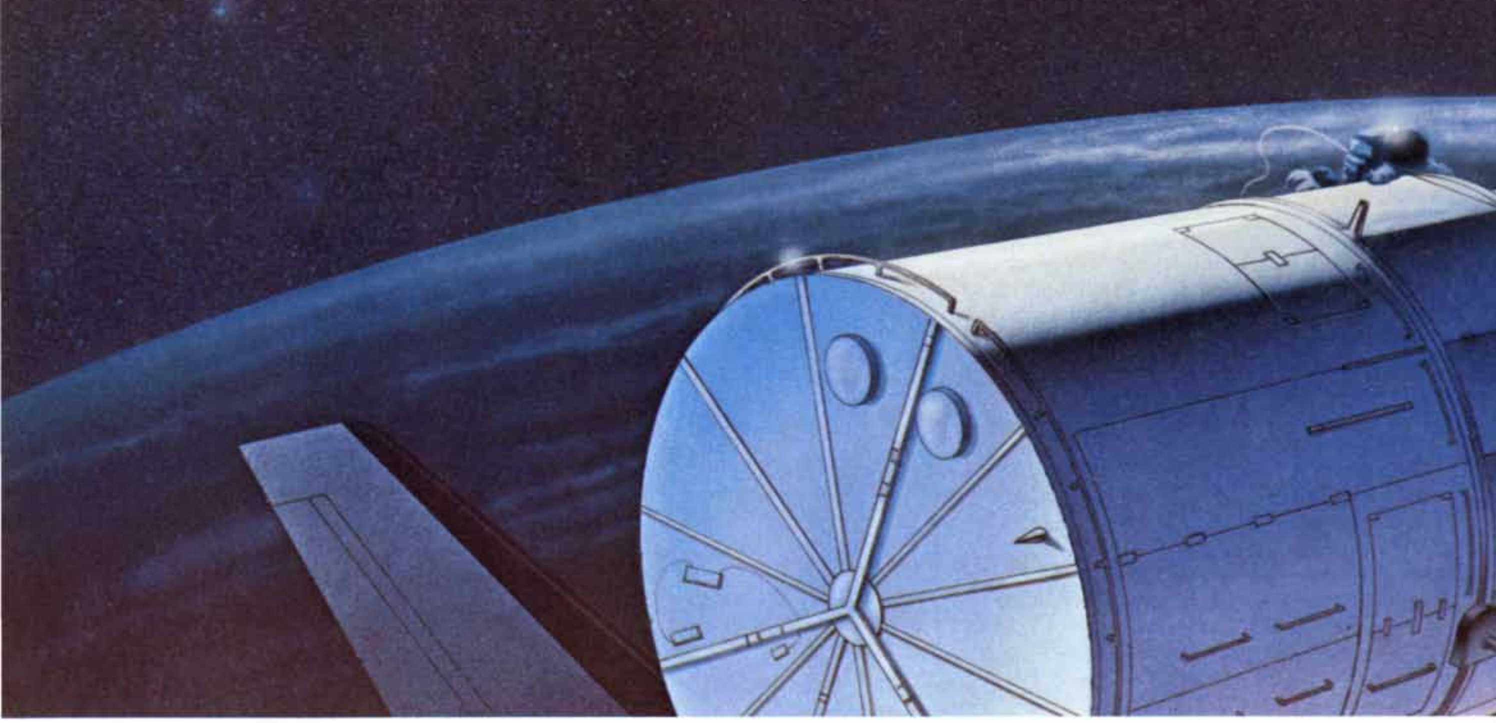
EARLIEST COSA LAMPS were all wheel-thrown. Three of the types (*A, B, C*) may have been made well before 273 B.C., the year Cosa was founded; they were among the votive offerings made to Jupiter by the settlers during the founding ceremonies. The first two types had handles. The third type, composite in style, had no handle; its body imitated an earlier Greek model but its nozzle was in the Roman style. The fourth type (*D*) appeared at Cosa between 225 and 200 B.C. Also handleless, it and Type C disappeared after 70 B.C. The fifth type (*E*) appeared between 120 and 70 B.C., when molded lamps are first found at Cosa. Types A, B and E continued in service at Cosa for some time after the introduction of molded lamps. Indeed, one Type A lamp comes from an archaeological context dated between A.D. 250 and 500.

In the years following the sack of Cosa the potters of central Italy gradually perfected an oil-lamp design that was to meet with great success as an export. This was the Roman "picture lamp," characterized by the presence of figures in low relief within the inner circle of the lamp top. Two examples of the type found at Cosa date to the town's resettlement in 25–20 B.C. or a little after it. Both lamps are of very high quality, suggesting that the design had been perfected at an even earlier date. One of them, perhaps the earlier of the two, has a triangular voluted nozzle with scrolls reaching a complex rim that frames the pictorial decoration. The other lamp has a longer, slender nozzle with a rounded tip and volutes with scrolls at both ends. Neither lamp has handles.

The relief decorations of the central area of Roman picture lamps, as we know from numerous examples found both in Italy and elsewhere, cover an enormous range of subjects. There are gods and goddesses, mythological animals such as griffins and sea horses and real animals such as fighting cocks, racehorses, circus horses, chariot horses, cart horses and solitary running horses. There are scenes from Homer and Virgil and from the labors of Hercules, gladiators in combat, hunting scenes and even erotic scenes. One popular decoration, found on lamps intended to be New Year's gifts, shows a winged Victory holding a shield inscribed with the message *Annu faustu felice tibi* (To you a happy and fortunate year). Surrounding the figure are depictions of bread, cakes, a flask of honey, coins and always one coin showing double-headed Janus, the demigod of beginnings and gateways.

On some lamps the Victory figure is

Creating an 'eye' that will see

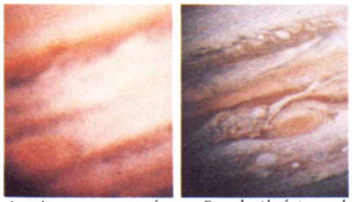


Lockheed knows how.

It's a project with promise that defies comprehension.

It's the NASA Space Telescope, managed by the Marshall Space Flight Center and being assembled and tested by Lockheed. It's scheduled for launch into 320-mile-high orbit by the Space Shuttle in 1985. And it will extend the observation reach of astronomers far out into the violent turmoil of space.

They'll look back about 14 billion light-years to where many think the universe edges lie. That's seven times farther than Earth-bound telescopes, hindered by atmospheric murk, have yet been able to see. And the telescope will find, lock onto, and study faint objects and masses only 1/50th as bright as any so far beheld.



Jupiter as seen from Earth (left) and through the clarity of outer space.

A masterpiece gets ready for action.

This astronomical observatory, the finest galactic telescope system ever built, will be a masterpiece of advanced technology in optics, instrumentation, communications, and pointing control.

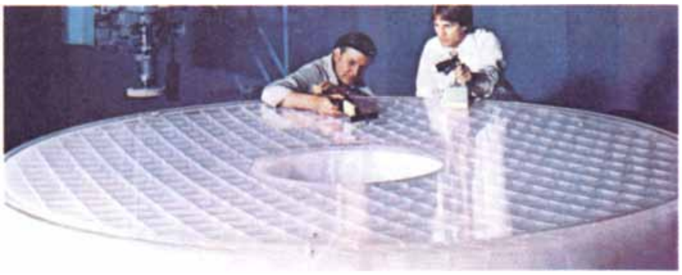
It will be large—43 feet long, 14 feet in diameter, and weighing about 24,000 pounds. When carried aloft, it will occupy the entire cargo bay of NASA's big-airliner-size Space Shuttle.

Once the telescope is deployed, its solar panels (being built by the European Space Agency) will unroll like long window shades, facing the sun to convert light into battery-stored electric power. High-gain radio antennas also will stretch out into position to work via relay satellites in communication to and from Earth.

And then the great instrument will go to work, its on-board computing and control systems already intricately programmed for the first viewing events.

The magnificent mirrors.

Capturing a wide spectrum of faint light (visible, red, blue, infrared, and ultraviolet) that has traveled billions of years is the job of the optical assembly (being built by Perkin-Elmer).

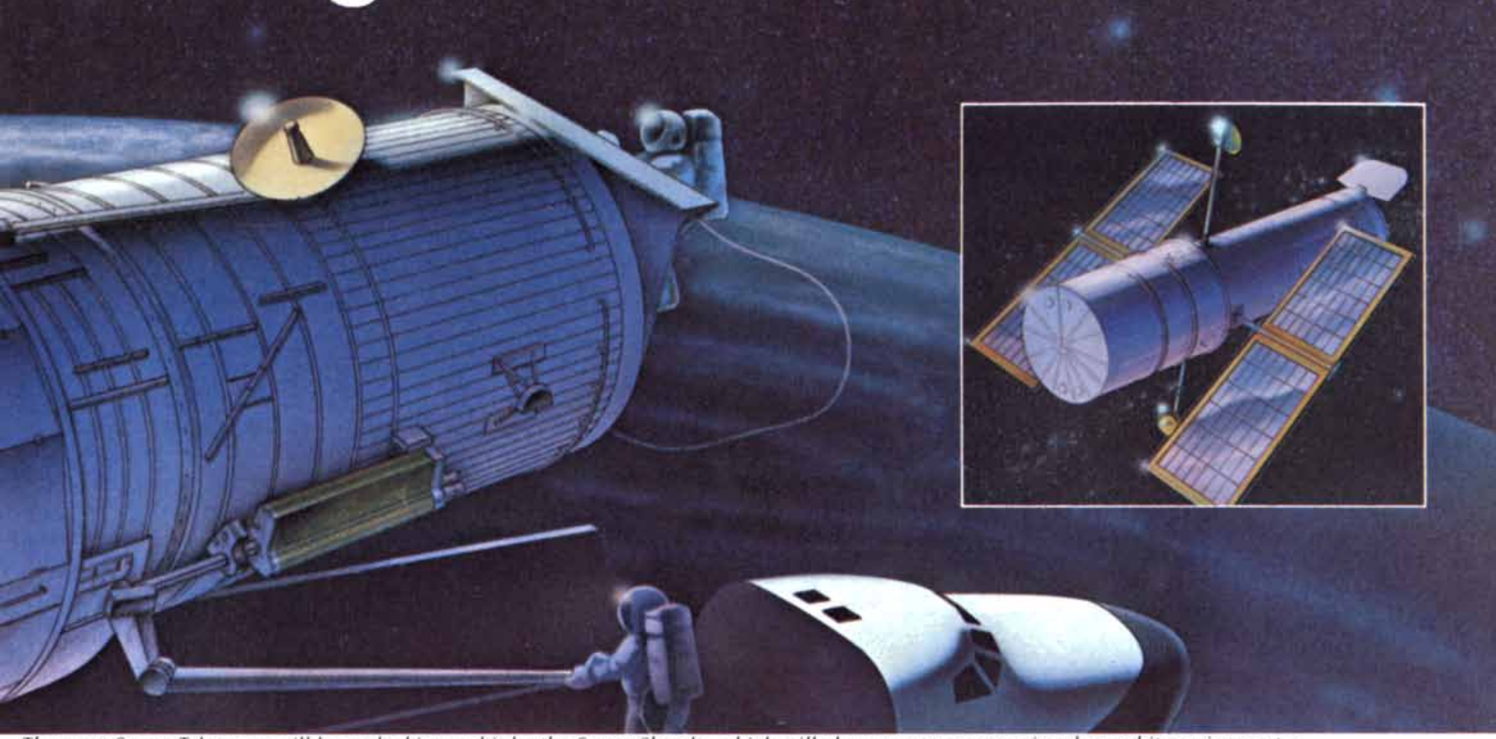


The extremely smooth, precisely shaped primary mirror surface will result from two full years of grinding and polishing.

A concave, foot-thick primary mirror, eight feet in diameter, will receive light coming in through the telescope's sun-shielded aperture. It will reflect and focus the light forward onto a smaller, facing mirror, which in turn will reflect the light back through a hole in the primary mirror's center. The final focal plane will be shared by a complex of guidance sensors and five scientific instruments . . . high-resolution cameras, spectrographs, and a photometer (being built by several institutions).

In their interference-free environment, the mirrors and instruments will help produce and transmit images with

the edges of the universe.



The great Space Telescope will be tucked into orbit by the Space Shuttle, which will also serve as an occasional on-orbit service center. INSET: The telescope deployed.

resolution 10 times greater than now possible with ground-based telescopes.

Fixing mankind's steadiest gaze.

Those mirrors and instruments, however, couldn't do their best without a unique Lockheed pointing control system (PCS) that positions and holds them precisely on target. And that is incorporated in the Lockheed Support Systems Module, containing the interfacing, communications, thermal control, data management, and electric power systems.

Using sensors and gyroscopic devices, the PCS will move and adjust the huge telescope into a programmed viewing attitude. The Perkin-Elmer fine-guidance sensors will fix upon a pair of known, bright 'guide stars,' references for finding the target.

When the target object is dead in the telescope's sight line, designated instruments will be turned on and other functions shut down. That's because the tiniest torque or motion in a small motor or electric relay could jar the 12-ton vehicle off its lock-on point.

And how precise is that lock-on? In angular measurement, there are 1,296,000 arc-seconds in a circle. For perhaps as long as 20 hours at a time, the telescope will hold onto a target with a stability accuracy of just *seven thousandths of one arc-second* in all directions.

That stability is 100 times greater than any ever achieved so far. It about equals standing in Boston and holding rifle sights steady on a dime suspended over Washington, D.C.!

Keeping a beauty in shape.

Lockheed's innovative design will also let the telescope have periodic 'house calls' for checkups and maintenance

In a neutral buoyancy tank, an astronaut goes through special training simulating the service tasks to be performed in space.

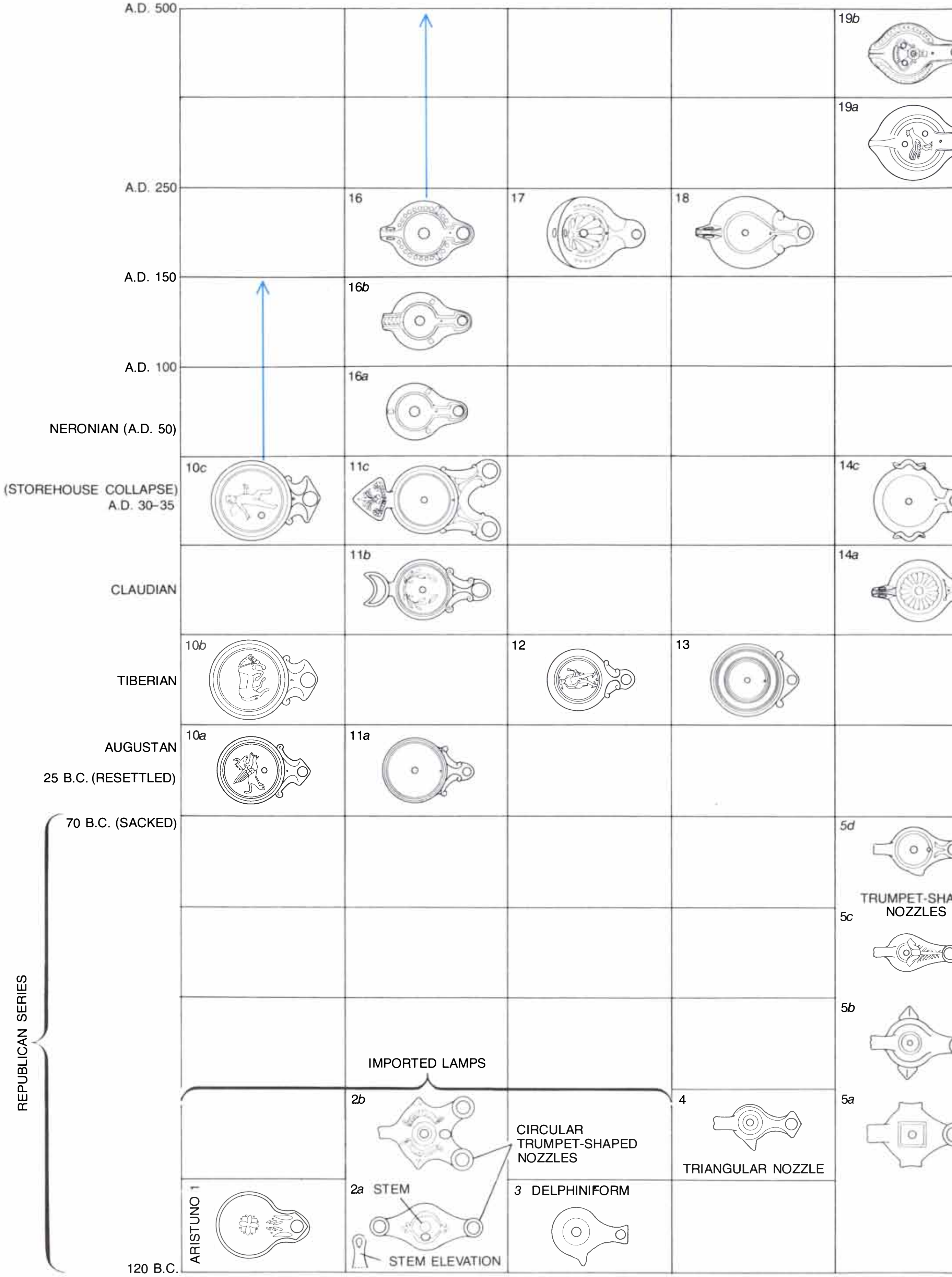
during its planned 15-year life. Armed with nothing more than a 7/16″ ratchet wrench and a Lockheed-devised foot-anchoring tool, a Space Shuttle astronaut will be able to open access doors, make inspections, replace modular units, and see to the telescope's well-being. When necessary, the Shuttle will retrieve the telescope and return it temporarily to Earth for general servicing.

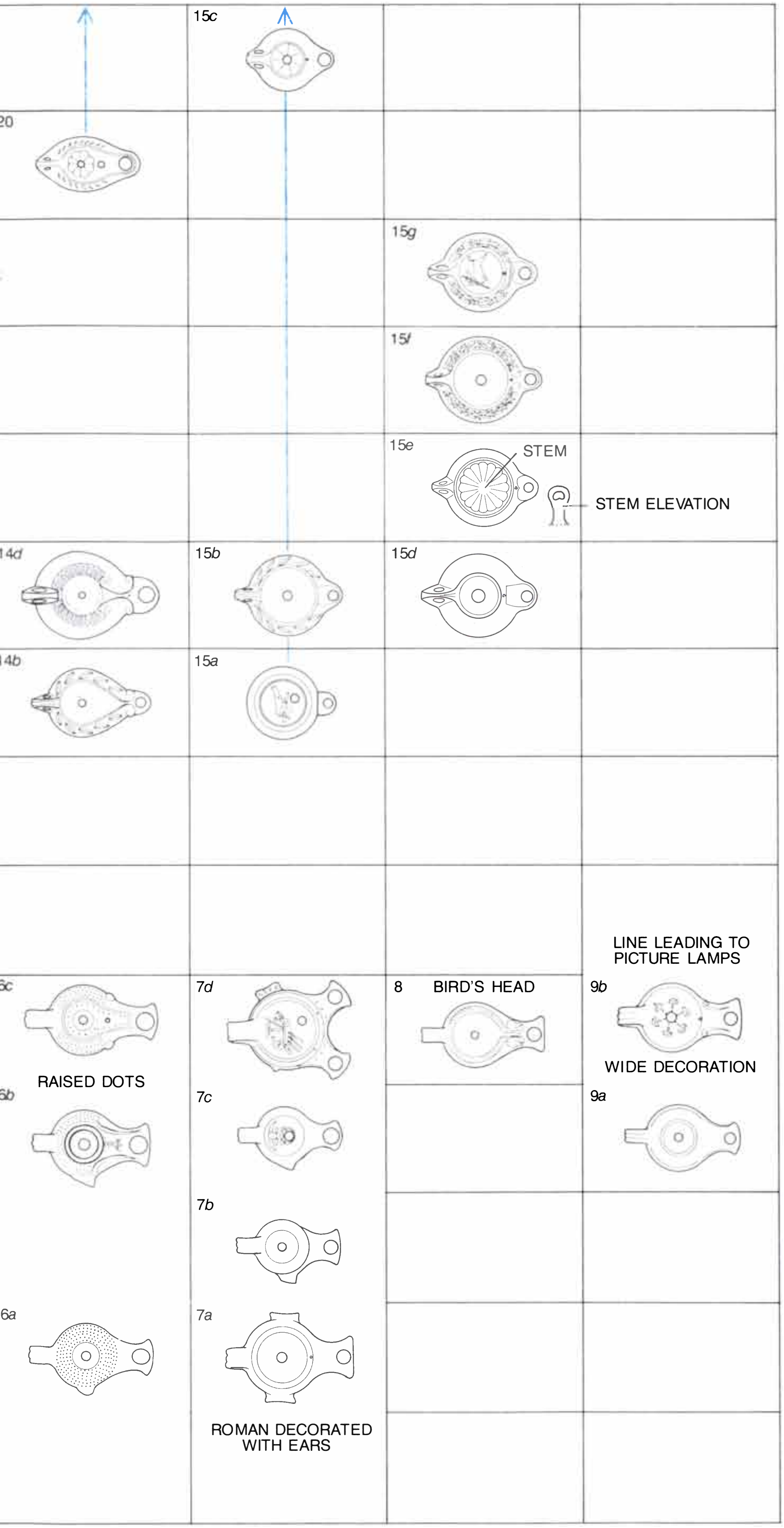
The world of science is waiting expectantly. The wonders yet to be discovered are waiting, too. The Space Telescope will arrange a meeting.

When it comes to bringing all this together—testing, refining, integrating all the critical elements of a miraculous scientific breakthrough—Lockheed knows how.

Lockheed

For more information about Lockheed, write for the 1981 Annual Report Highlights to A.F. Melrose, Lockheed Corporation, P.O. Box 551, Burbank, CA 91520.


A.D. 500
A.D. 250
A.D. 150
A.D. 100
NERONIAN (A.D. 50)
(STOREHOUSE COLLAPSE) A.D. 30–35
CLAUDIAN
TIBERIAN
AUGUSTAN
25 B.C. (RESETTLED)
70 B.C. (SACKED)
REPUBLICAN SERIES
120 B.C.
19b
19a
16
17
18
16b
16a
10c
11c
14c
11b
14a
10b
12
13
10a
11a
5d
TRUMPET-SHA
NOZZLES
5c
5b
IMPORTED LAMPS
2b
4
5a
CIRCULAR TRUMPET-SHAPED NOZZLES
TRIANGULAR NOZZLE
ARISTUNO 1
2a STEM
3 DELPHINIFORM
STEM ELEVATION



not surrounded by gifts, and her shield bears wishes for the common good. One such inscription reads *Fides publica* (The public trust), another *Ob cives ser* (For the preservation of the citizenry). Still other picture lamps bear portraits of the rulers of Imperial Rome. The emperor Septimius Severus, who ruled from A.D. 193 to 211, appears on one such lamp together with his wife, Julia Domna, depicted respectively as Sol and Luna (the sun and the moon).

The part of Cosa that has proved richest in lamps is the array of public rooms, shops and storage rooms that constitutes one *atrium publicum*. (Eight such atriums surrounded the Forum.) The earliest lamps found here date to about 200 B.C. and the latest to about A.D. 500. The real treasure trove at the atrium, however, was the storeroom of a hardware shop. It had been crushed shortly before A.D. 30 or 35 by the collapse of an adjacent building. When academy archaeologists cleared the area in the 1950 season, they uncovered a staggering number of broken lamps. It has proved possible not only to piece together entire lamps out of this debris but also, when the lamp was decorated with a relief, to reassemble enough fragments to reveal much or all of the shattered picture on it.

The storehouse debris yielded numerous examples of still other types of Roman lamp. The first is a "triangular nozzle" lamp. It reveals a stylistic evolution from early versions with long, narrow nozzles to lamps with progressively wider nozzles. A second narrow-nozzle design, contemporaneous with the first, had when it was fully evolved a short, strong nozzle with ornate scrolls that look rather like facing pouter pigeons.

Other evidence of innovation at this time is to be found in lamps with long nozzles and "heat shields" on their handles. Many of these lamps had twin nozzles; one of them had seven. The lamps must have been hard to make and easy to break; they seem to push the shape of a lamp that could be made with a two-piece matrix to its limits. One may say, perhaps, that they represent the baroque period of Roman lamp design.

The storeroom fragments reveal that a far more conservative type of lamp appeared at this time, probably in the last decade before the collapse of the

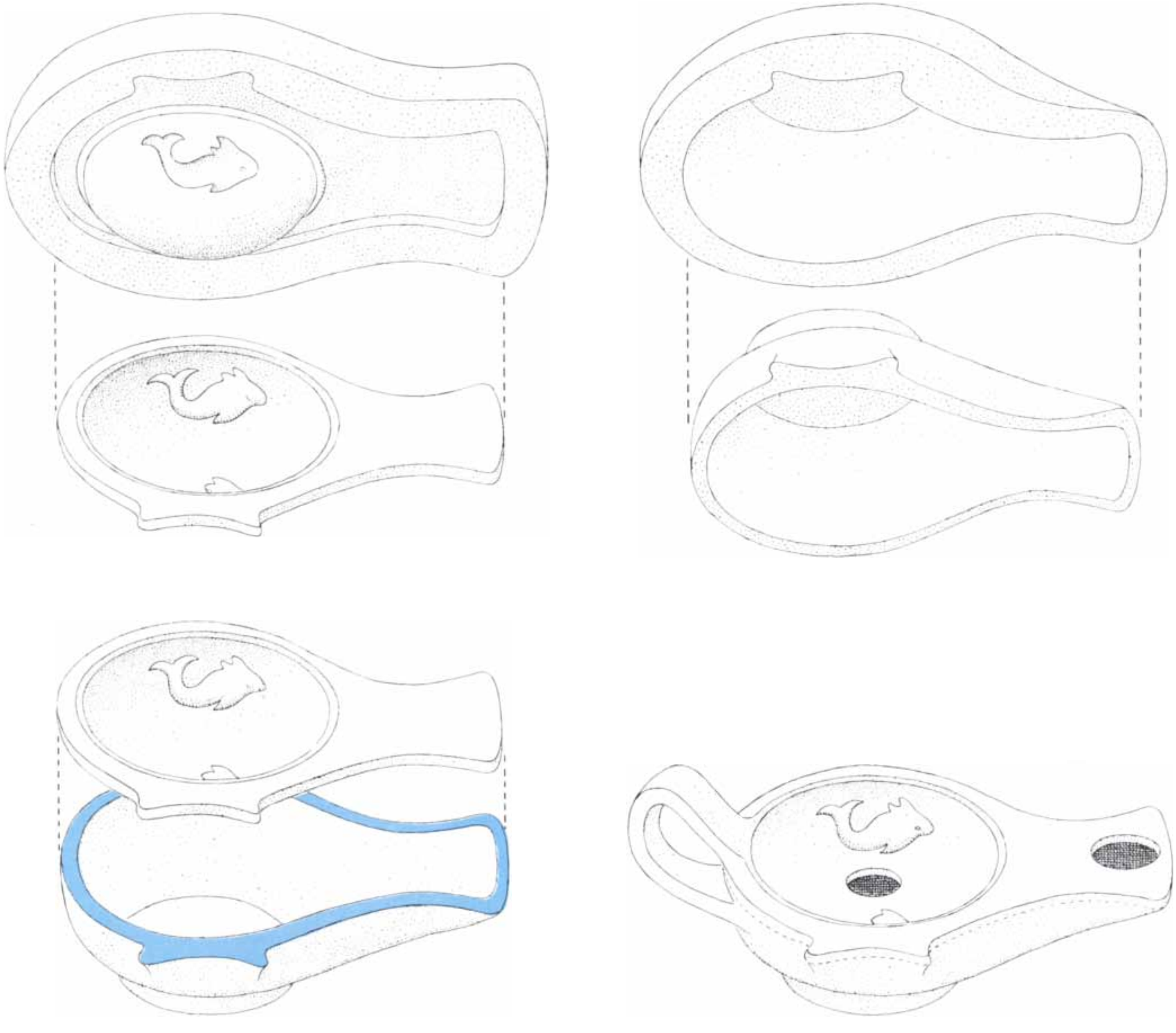
MOLDED LAMPS uncovered at Cosa can be placed in various historical contexts, starting with the Republican period (120–25 B.C.) at the bottom of the chart at the left and ending in A.D. 500 at the top. Twenty lamp varieties are represented by the 46 top views of lamps seen here. Three varieties, in categories 10, 15 and 16, continued to be made over the period indicated by the arrows in color. Four lamp varieties (1, 2, 3 and 19) are imports.

adjacent building. The lamp's handle was an integral part of the mold design and its shoulder had a downward slope. Its nozzle was of a new kind: short, rounded and joined to the shoulder without volutes. The type enjoyed centuries of popularity and was exported (and often copied) throughout the empire. At first its relief decoration was limited, as it was in more traditional picture lamps, to the framed area of the top, but by A.D. 150 the decoration had extended to the sloping shoulder as well.

A completely new type of molded lamp appeared at Cosa between A.D. 50 and 70. It was produced in northern Italy (one factory being at what is now Modena) and has come to be known as the "factory lamp." Its patrix seems to have been a bronze lamp with three evenly spaced suspension lugs rising from its shoulder, so that it could be hung on chains from the ceiling or from a wall bracket. The matrix and the molded lamps at first faithfully reproduced the lugs. The makers of the factory lamps even pierced holes in the clay lugs during the assembly process, but this touch of verisimilitude was eventually dispensed with, and as the years passed the lugs degenerated into mere rounded bumps on the shoulder.

This plain, strong lamp was easy to pack for shipment (a crate of the lamps, still packed, was found at Pompeii). It was also cheap: unskilled slave labor could line the matrixes with clay and assemble the drying molds. Even turning out the matrixes themselves could be left to semiskilled workmen. As a result factory lamps were produced by the thousands and captured the lamp market not only in northern Italy but also in central Italy and the northern and western provinces of the empire. (For some unknown reason not many reached the eastern and southern areas of the Mediterranean.) Factory lamps continued to dominate the market for more than two centuries. Before the end of the second century A.D. they were being made locally in Gaul, in Germany and even in Britain.

Whereas most of the lamps of Cosa were made elsewhere, some of the wheel-thrown Type E lamps appear to be of local manufacture. This conclusion is based on the kind of clay used and also on a circular or oval stamp



MASS PRODUCTION OF LAMPS became possible with the adoption of molds for forming separate upper and lower halves. At the left is a sturdy matrix, with its negative central decoration; below it is the lamp top formed by packing a thin layer of soft clay into the matrix. At the right is a similar matrix for the lamp bottom; below it is the lamp bottom, ready for joining to the top. At the bottom (*left*) the two parts are being joined; a clay slurry (*color*) is the cement. The finished product, with its nozzle and filler holes cut out, is at the right.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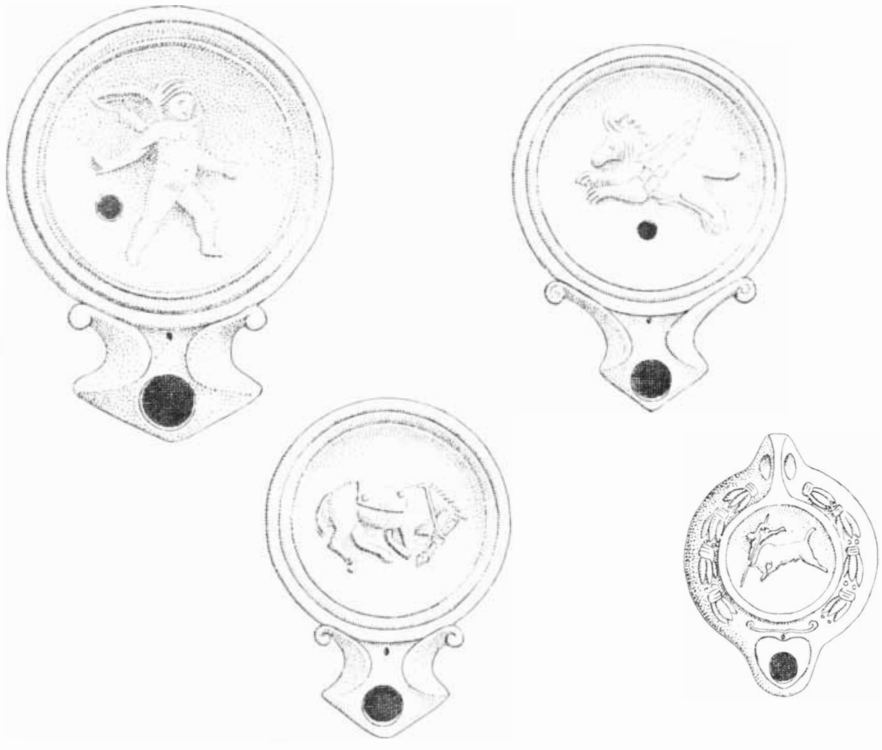
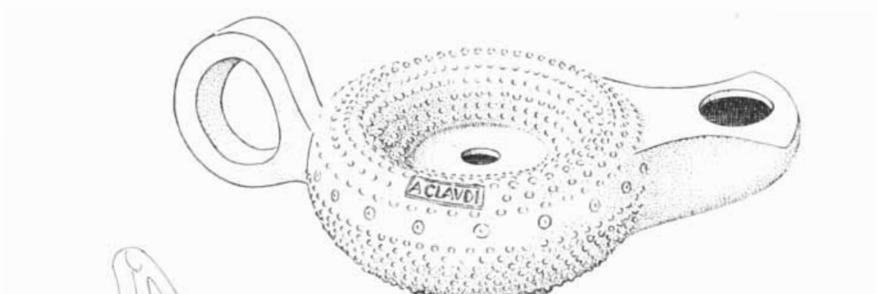
mark on the top of the lamp nozzle. Inside the stamp mark is either the letter *S* or the letters *SL*. It happens that members of a family named Sestius were residents of Cosa for several generations. They are known to have manufactured the traditional two-handled storage jars called amphoras. Perhaps when the demand for storage jars was slack the Sestius workshop turned to producing oil lamps and other crockery.

Only one full name appears on any of the Roman lamps found at Cosa. Impressed on the top of one of the molded lamps with raised-dots decorations (rather than on the base, as was custom-

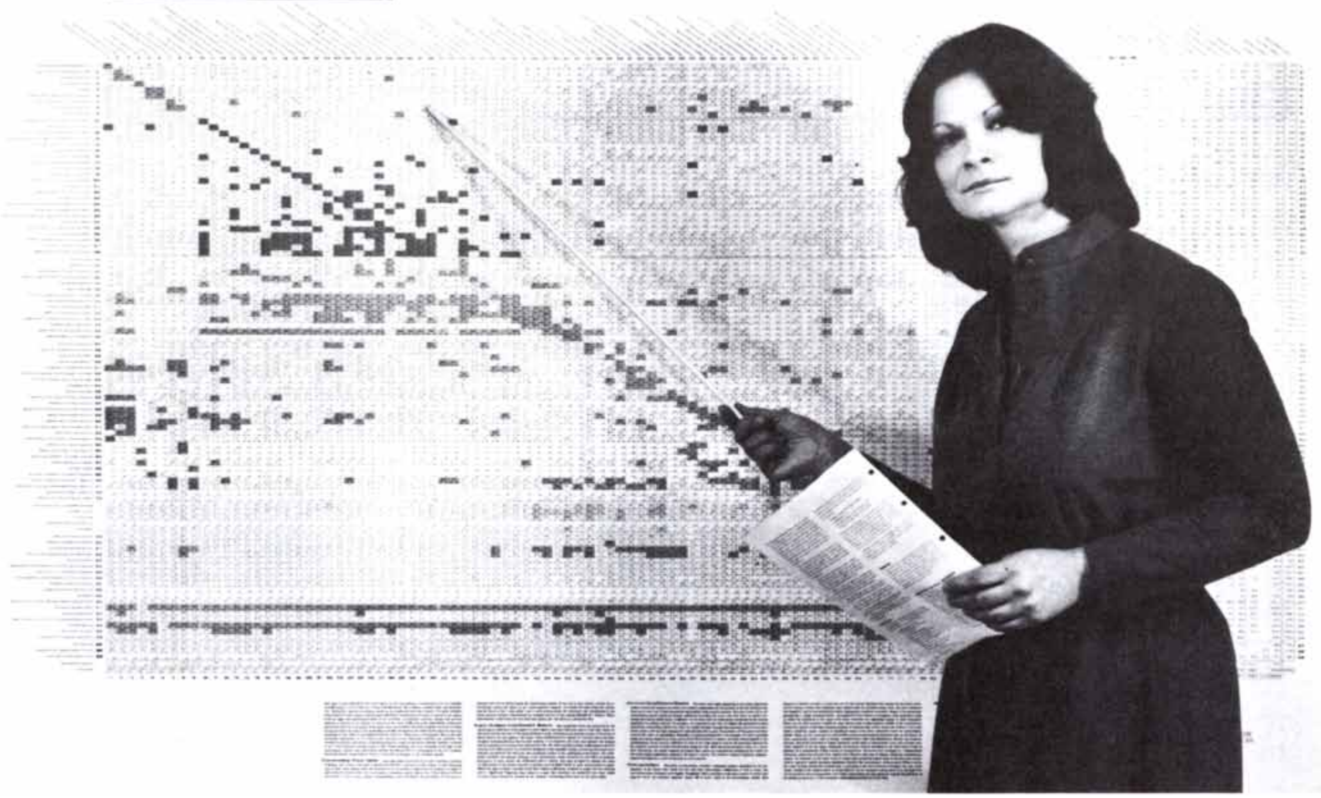


"PICTURE LAMP" DECORATIONS, typical of the various themes depicted on these popular molded lamps, included among other mythological figures Cupid (*top left*) and griffins (*top right*). Horses (*bottom left*) and circus acts (*bottom right*) were also popular decorations.



EARLY MOLDED LAMP, popular at Cosa, was a Roman product decorated with rows of raised dots (*top*). This particular "raised dots" lamp is one of the few at Cosa that bore a potter's name. The lamp with twin nozzles (*bottom*) is one of several new types of Roman lamp that appeared at Cosa in A.D. 30–35. One of the multiple-nozzle lamps had seven nozzles.

THE INPUT/OUTPUT STRUCTURE OF THE UNITED STATES ECONOMY



WHAT MAKES THE U.S. ECONOMY TICK?

The editors of SCIENTIFIC AMERICAN have prepared a wall chart displaying for the 1980's the Input/Output Structure of the U.S. Economy based on the latest interindustry study from the U.S. Department of Commerce.

The SCIENTIFIC AMERICAN Input/Output wall chart does for economics what the table of elements does for chemistry. It answers at a glance questions about the linkage between the microeconomics of the firm and the macroeconomics of the system; about the web of technological interdependencies that tie industry to industry; about the industry-by-industry direct and indirect consequences of swings in public and private spending; about the impact of change in technology, and about any other topic you can think of. You are rewarded by surprise as well as by confirmation of your hunches. For teaching and practical and theoretical studies, here is a powerful, graphic tool.

In the familiar format of the SCIENTIFIC AMERICAN Input/Output wall charts for the 1960's and 1970's, the wall chart for the 1980's measures 65″ × 52″ and is printed in eight colors. Each of the nearly 10,000 cells in the 97-sector interindustry matrix shows (1) the interindustry commodity flow, (2) the direct input/output coefficient and (3) the "inverse" coefficient. Where the direct input/output coefficient exceeds .01, the cell is tinted in the color code of the industrial bloc from which the input comes. This device, combined with triangulation of the matrix, brings the structure of interindustry transactions into graphic visibility.

A supplementary table displays, industry by industry, the capital stock employed; the employment of managerial, technical-professional, white-collar and blue-collar personnel; the energy consumption by major categories of fuel, and environmental stress measured by tons of pollutants.

The editors of SCIENTIFIC AMERICAN are happy to acknowledge the collaboration, in the preparation of this wall chart, of Wassily Leontief, originator of input/output analysis—for which contribution to the intellectual apparatus of economics he received the 1973 Nobel prize—and director of the Institute for Economic Analysis at New York University.

Packaged with the chart is an index showing the BEA and SIC code industries aggregated in each of the 97 sectors.

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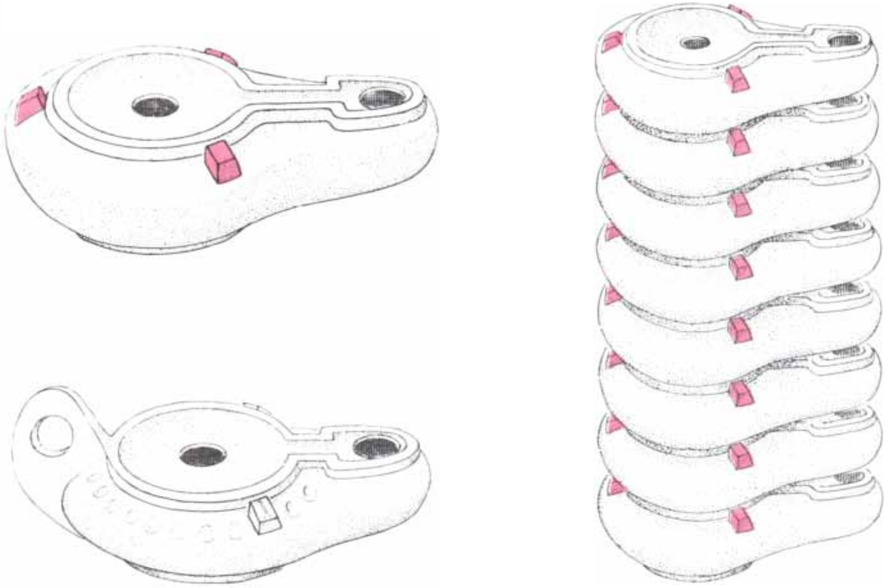
ary) is the name A CLAUDI. There is no clue to where the Claudi workshop was. Not long before A.D. 50 three other names begin to appear on the bases of Cosa lamps but in abbreviated form. One of these is COPPIRES (alternatively COPRESTI), with the probable reading *Caius Oppius Restitutus.* Another is LFABRICMAS (alternatively LFABRICMASC), with the probable reading *L. Fabricius Masculus,* and a third is LMADIEC, with the probable reading *L. Munatius Adjectus.* The majority of the lamps found at Cosa, however, bear no identifying marks.

The last centuries of Cosa's existence were a time of slow decline and a decay of the quite high standards maintained under the emperor Hadrian (A.D. 117–138). With the exception of a few poor copies of earlier Roman lamps, the lamps at Cosa dating from A.D. 250 to 500 are crude imports from North Africa.

Thirty of the lamps of this late period are of particular historical interest. They were found in a shrine of Bacchus that had survived for decades after the emperor Theodosius' edicts outlawing paganism in A.D. 391–92. The end of the shrine and the cult of Bacchus at Cosa had evidently been violent. The shrine furnishings, which included a fine first-century statue of Bacchus as a youth, ritual vessels decorated with snakes crawling up the handles, and the 30 lamps, had all been broken and abandoned, and the head of the statue had been carried away. The debris had at first been covered by wind-driven soil and later by the fallen roof and walls of the shrine. Coins found in the ruins by the academy excavators suggest that the destruction took place in about A.D. 500.

What kind of performance can one expect from an oil lamp? On various festive occasions at Cosa academy archaeologists have put two of the intact wheel-thrown lamps (a Type B and a Type C) to use. They made wicks for the lamps by braiding together eight cotton threads from a modern fisherman's lantern wick. Both types of lamp burned with a tall flame that ended in a blue point with little or no smoke. The flames were brighter than a candle's and lasted for about two and a half hours on a single filling of olive oil.

The Cosa lamp collection is significant, however, not because of the lamps' performance, manufacture or artistic qualities, or even because some lamps found at Cosa are very rare elsewhere in the Roman world. Its significance lies first in the fact that the lamps display the fashions and even fads in artificial illumination in a typical small provincial Roman town over more than seven centuries. This is one of the longer spans of time known so far in the material evidence of Classical archaeology. The Cosa collection is a broad cross section of the products of an international industry in the Mediterranean basin that flourished, declined and flourished once again during a long and significant interval in ancient history. Finally, when the inventory of the Cosa lamp becomes available to Classical scholars in general, it should be of help in determining the dating of other Mediterranean lamps found in less clearly established contexts.



"FACTORY LAMP," a cheap, plain, strong product made in northern Italy, appeared at Cosa soon after A.D. 50. Its prototype was evidently a bronze lamp with three suspension lugs (*color*); these were at first faithfully copied in the pottery versions. Easy to make and easy to pack for shipment (*see nesting detail at right*), factory lamps dominated the market for more than a century. The simple version at top left later gained a handle and modest decorations (*bottom left*).

THE AMATEUR SCIENTIST

What happens when water boils is a lot more complicated than you might think

by Jearl Walker

The sound of water being boiled for coffee or tea is so familiar to me that I hardly notice it. Yet I can always tell by the sound when the water is at full boil and ready for pouring. Interpreting the details of what takes place in the container requires a good deal more attention and is actually quite difficult. Nevertheless, much of the thermodynamics is now understood. It reveals that more is going on than meets the eye or ear.

Much of my discussion of this phenomenon is drawn from *A Heat Transfer Textbook,* by John H. Lienhard of the University of Houston. A useful adjunct to the discussion is a graph relating the heat flux (the rate per unit of area at which heat is transferred to the water) to the difference in temperature between the pan (mainly the bottom of it) and the bulk of the water. The temperature of the bottom of the pan goes above the temperature of the water and gives rise to convection in the water and eventually to evaporation.

I supposed such a graph would show a simple curve indicating that the amount of energy transferred to the water increases with the temperature of the pan. Instead the curve rises to a peak, falls rapidly and then rises again. At the lower temperatures the heat flux does increase with the temperature, but just beyond the peak the flux drops radically.

The temperature of the water and of the bottom of the pan is often measured with respect to the normal boiling temperature of the water at the existing pressure. The result is known as the saturation temperature. Water at the boiling temperature is said to be saturated. When water is heated above the saturation temperature but does not change in phase from a liquid to a gas, it is said to be superheated. In the accompanying graph [*page 168*] the temperature scale records the difference between the temperature of the bottom of the container and the saturation temperature of the water.

One might think that in the early heating stages the water layer just above the heated surface would quickly reach saturation temperature. In such a case it would form bubbles of vapor. Convection, however, keeps the water temperature below the saturation temperature. The heat that is added decreases the density of the water, forcing it to move upward because of its buoyancy. The cooler water descends to the bottom and is heated.

The heat transferred to the water is thus carried to the top by convection. At the top the water can change its state. If the heat flux is low enough, this type of transfer continues until all the water vaporizes off the top surface.

With a larger heat flux the boiling process soon reaches the stage called nucleate boiling. At first isolated bubbles form on the bottom of the pan. If the source of heat is more powerful than a kitchen stove, the water reaches another stage: freshly formed vapor bubbles from many sites merge into columns, jets and slugs of vapor that rise to the top and escape. In both stages of nucleate boiling the formation of vapor bubbles increases the transfer of heat away from the heated surface.

If you boil fresh water on a stove, two types of bubble appear in the first stage of nucleate boiling. One is a vapor bubble. The other is a bubble formed out of the air dissolved in fresh water. As the water is heated the air is driven out of solution and into bubbles that form at isolated places on the bottom.

The two types of bubble are easily distinguished by what they do. An air bubble remains stable on the bottom until it breaks loose and rises. Vapor bubbles, which are blurry, form and collapse and then re-form from 30 to 60 times per second. Even if they break loose from the bottom and start to rise, they collapse in the cooler water above them. (This stage is termed subcooled boiling because only the bottom layer of water is saturated or superheated.) Water that has been heated previously, either on the stove or in the hot-water system of the building, does not develop air bubbles because most of the air has been eliminated.

In the early stage of nucleate boiling isolated vapor bubbles also begin to appear at certain places on the bottom. These places are nucleating sites. They generate many bubbles, but each one collapses soon after it forms or as it begins rising into the cooler water above. With a continued heat flux the water well above the heated surface eventually gets hot enough for the bubbles to be able to rise farther. If they reach the surface, they burst and release their vapor.

Much of the vaporization in a bubble takes place during the ascent through the superheated liquid. One might suppose most of the heat transferred from the bottom of the pan would go into the formation of bubbles there. Instead most of it goes into the water touching the bottom, either in the regions between the sites of bubble formation or in the inflow of water at one of those sites after a bubble has collapsed or has been released.

At the higher temperatures of nucleate boiling the bubble sites on the bottom of the pan are much more numerous. The bubbles almost immediately merge into columns, jets and slugs of vapor that linger just above the sites of formation. In this phase of boiling the heat is transferred to the water at a high rate. Bubbles form and leave the bottom so rapidly that gushes of cooler water are carried to the bottom to be heated.

The rapid drop in flux is reached at a somewhat higher temperature. This stage is termed the transition boiling regime. It is dangerous in industrial cooling systems if the heat continues to be delivered to the container; heat transfer to the water suddenly declines. The increased temperature can damage the container. Hence the transition boiling regime is also called burnout or the boiling crisis.

In the transition boiling regime an increase in the temperature of the container actually leads to a suppression of the amount of heat carried away by the water. The cause is vapor that develops over the bottom of the container. Heat is transferred slower through vapor than it is through water. The higher the temperature of the container, the more extensive the vapor and the poorer the transfer of heat.

At the very-high-temperature stage of boiling the heat flux rises again as the temperature increases. In this stage, termed film boiling, a constant layer of vapor lies over the bottom of the container. Although the heat flux is poor at first because of the vapor, the high temperature eventually drives the heat through the layer.

Water boiled on a kitchen stove does not, however, reach these high-tempera-

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ture phases. Nevertheless, all the characteristics of boiling can be observed up to the region of isolated bubbles. Lienhard suggests the following experiments. Put a pan of cold tap water on a stove burner turned to its highest intensity. After a while you will see some of the circulation that results when heated water leaves the bottom of the pan and rises toward the top. The circulation is visible because the differences of density created in the water by the heating give rise to variations in the index of refraction of the water, distorting the paths of the light rays reflected from the bottom.

Air bubbles soon appear on the bottom, probably over the hotter places. On my electric stove the coils heat from the outside inward. I can tell when the inner coils begin to heat by watching the distribution of air bubbles. In order to achieve a more uniform heating I insert a piece of aluminum (a quarter of an inch thick and slightly wider than the pan) between the coils and the pan. A thicker piece would work better.

Soon after the air bubbles appear the pan begins to "sing." The sound marks the rapid creation, oscillation and collapse of vapor bubbles on the bottom. When a bubble collapses, it makes a sharp ping or click. (Air bubbles do not emit sound because they do not collapse.) As the water continues to heat up, more of the vapor bubbles give their note of collapse and the pan makes quite a racket. I know from experience, however, that the noise does not mean the water is hot enough for coffee or tea.

The noise gradually abates as more of the vapor bubbles survive their ascent through the cooler water and reach the top. There they burst with a small splash. The burbling that now results is the sign the water is ready, being at full rolling boil.

Lienhard says the bubble motions can be observed more closely with a stroboscope. Heat the water in a Pyrex beaker. (Ordinary glass may shatter from the heat.) Set the stroboscope to flash at a frequency of from six to 10 hertz. Put a piece of tissue paper or frosted glass in front of the stroboscope to diffuse the light. With the room lights off you can slow the bubble motions on the bottom of the container.

The generation of bubbles starts in the tiny pits and short cracks on the bottom of a container. Although the bottom of a metal pan may appear to be smooth, it is covered with such small irregularities. Some of them trap air when water is first poured into the pan. Surface tension then prevents the water from entering them. The tiny pockets of trapped air serve as the nucleating sites for the air and vapor bubbles that develop as the water is heated. A vapor bubble grows at a nucleating site as superheated water vaporizes into the air in the pit.

Theoretically there is an equilibrium at the radius of the bubble. At that point the vapor pressure in the bubble matches the external pressure from the overlying water and the surface tension of the water at the interface between the bubble and the water. Usually, however, the bubble is unstable in the sense that if any perturbation makes the radius smaller, the surface tension overwhelms the internal vapor pressure, causing the bubble to collapse. If something makes the radius larger, the liquid at the interface vaporizes into the bubble, causing the bubble to grow.

The theoretical value for the radius of a stable bubble depends in part on the temperature of the surrounding water. At first the water is not much superheated. The stable radius is large, with the result that the growth of bubbles is rare since most of the nucleating sites are occupied by small bubbles. As the temperature of the water increases, the value for the stable radius decreases. The formation and the growth of bubbles become likelier.

When the temperature of the water increases, the heat flux into the water also increases, at least in the stage of isolated bubbles. The increased influx of heat does not go directly into the bubbles. Rather the bubbles act as tiny pumps that continuously bring cooler water in contact with the heated surface of the pan.

Suppose the water is not hot enough

John H. Lienhard's photograph of acetone boiling in two stages over a heated wire: nucleate boiling **(left)** *and film boiling* **(right)**

to allow a bubble to escape toward the top. The bubble, situated over a nucleating site, has a radius larger than the radius for a stable bubble. Therefore it grows as water vaporizes into it. The bubble's growth, however, pushes its top surface up into cooler water. There vapor condenses even as water continues to vaporize at the heated surface. The top of the bubble begins to collapse and then the entire bubble collapses. The collapse drives a tiny circulation, with the superheated water at the bottom of the bubble springing up and the cooler water at the top dropping down. The cooler water is then heated. This circulation increases the rate at which heat is transferred to the water.

Later in the heating process the vapor bubbles break free of the heated surface. As a bubble grows over its nucleating site it absorbs heat from the surrounding superheated liquid. When the bubble escapes, it entrains in its wake cooler water from higher above the heated surface. That circulation of cooler water enhances the heat flux into the water. The heat flux is further enhanced because in this later stage of nucleate boiling more nucleating sites are active.

The actual rate of heat transfer to the water in nucleate boiling depends in part on the nature of the heated surface. A bubble tending to form at a nucleating site has a radius partly determined by the size of the pit at the site. Large pits or pits with flat bottoms, however, are relatively ineffective in bubble nucleation. The smaller the pit, the smaller the bubble that tends to form over it. Particularly small pits, however, probably have no role in the initial onset of bubble generation. The bubbles that form in small pits are smaller than the radius for stability and therefore tend to collapse. As the water temperature near the heated surface increases, the radius for a stable bubble decreases and the smaller pits become more active.

In general the heat flux at a particular temperature is greater for a pan with a rough inside bottom surface than it is for one with a smooth, polished surface. I experimented with one of my steel pans heated by a piece of aluminum on an electric stove. The bottom of the pan had been scratched by years of service and scouring. When I heated fresh, cool tap water, air bubbles collected near the perimeter of the pan, apparently because the outside bottom surface made the best contact with the aluminum in that area.

I could clearly see the network of old scratches on the inside surface, but the air bubbles did not reflect that pattern. Instead they were spread out rather uniformly, as were the vapor bubbles. Apparently the old visible scratches were too large to take part in the formation of bubbles.

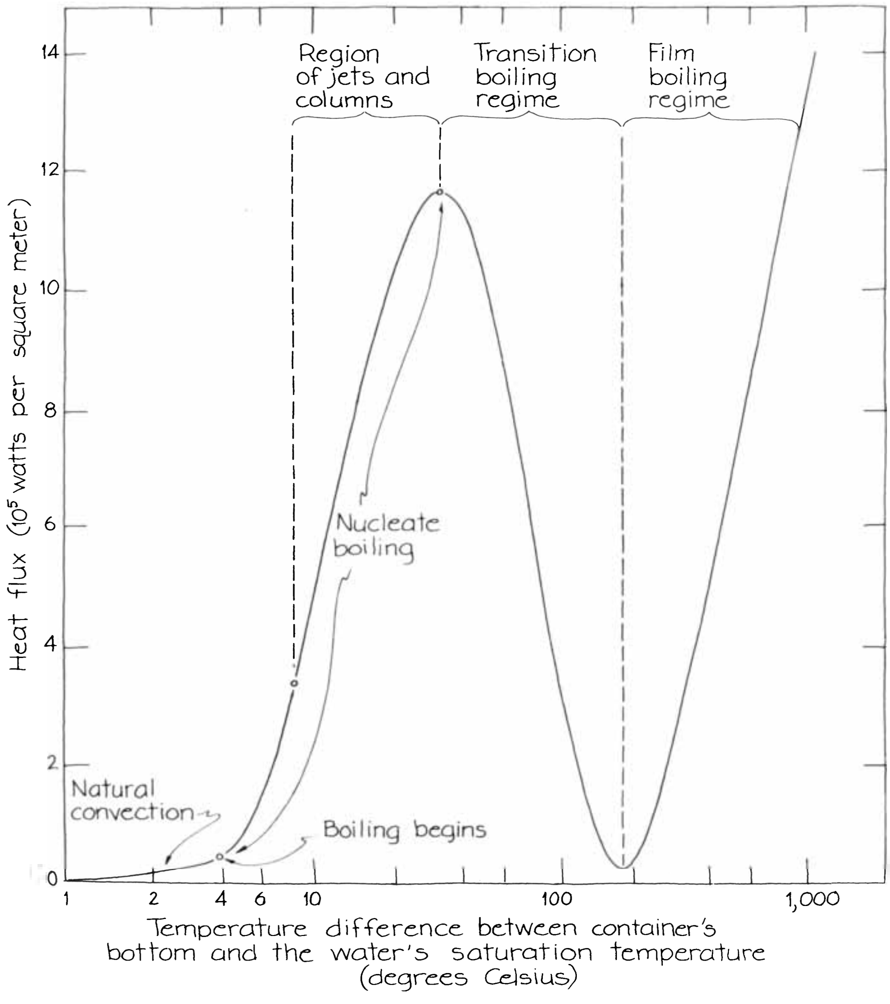
As the pan heated further, the formation of bubbles extended inward toward the center. Once the vapor bubbles near the perimeter began to form rapidly, however, the activity nearer the center diminished and eventually disappeared. Why did it? Surely the piece of aluminum was then hotter than ever. I believe this oddity was due to the rapid heat flux in the ring at the perimeter. Bubble nucleation began in that ring. Once the vapor bubbles were able to break free the heat flux in the ring was significantly higher than the heat flux toward the center. The ring drained enough heat from the underlying piece of aluminum to make the water nearer the center of the pan unable to superheat sufficiently to continue bubble nucleation.

I emptied the pan and reheated it briefly to dry the inside. Then I made scratches in three areas near the perimeter. In one area I stroked twice with a ball of steel wool. In another I made two hard scratches with the tip of a steel screw. Next to them I made a double scratch with the pointed tip of an aluminum rod. Then I refilled the pan with cool tap water and heated it.

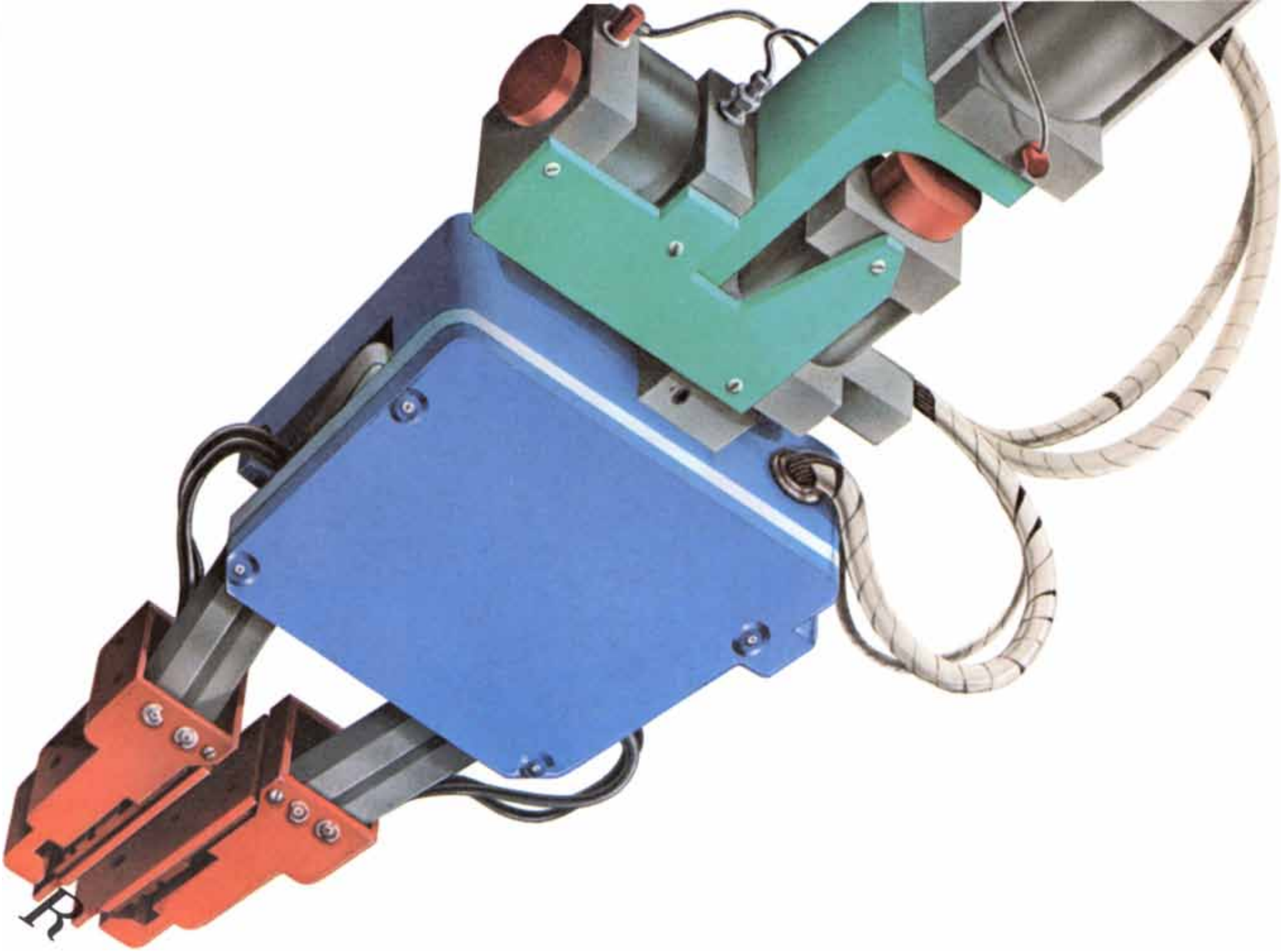
The generation of bubbles in the region stroked with steel wool was the same as it was in the unaltered regions near the perimeter. The screw scratches were also seemingly ineffective in nucleating bubbles. Although bubbles appeared nearby, they seemed to be unrelated to the scratches. The shallower scratches made by the aluminum rod gave rise to lots of bubbles, first of air and then of vapor.

I could not see well after the water began a rolling boil, and so I occasionally picked up the pan to reduce the boiling. Although bubble generation elsewhere disappeared almost immediately, at the scratches from the aluminum rod they continued for 20 or 30 seconds. I cannot believe the scratches from the rod were in fact nucleating bubbles; they were too large. It is more likely that the rod skipped a little as I scratched the surface, gouging small pits in the scratch that served as nucleating sites.

The mechanics of bubble growth in a surface irregularity can be modeled by considering a conical pit in the heating surface. Initially the air trapped in the pit is covered by an upwardly curved water surface at the top of the pit. The gas is at the same temperature as the surrounding water. The pressure inside



The three stages of boiling



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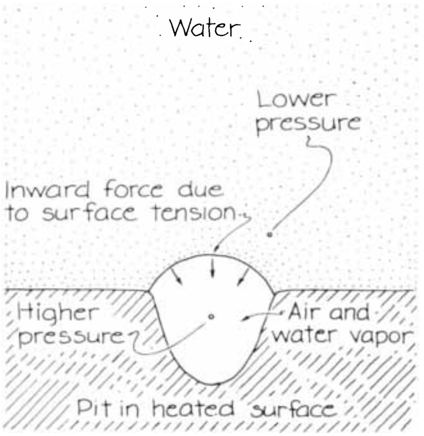
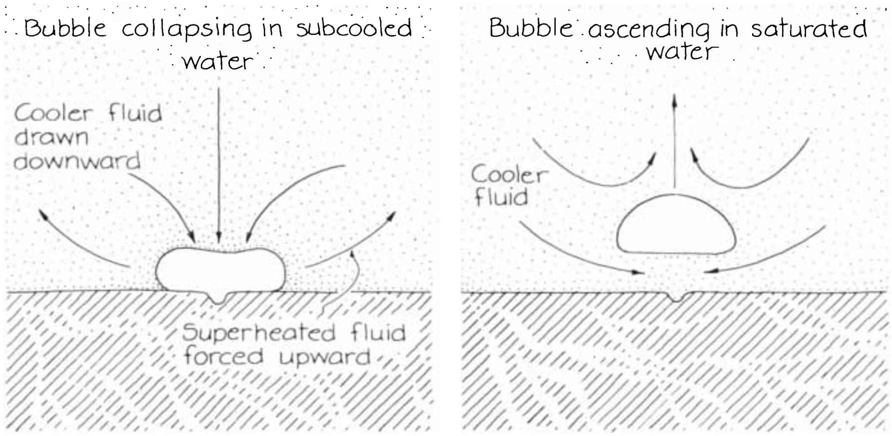


Pressures in and on a bubble



The patterns of circulation resulting when a bubble collapses **(left)** *and rises* **(right)**

the gas pocket is higher than the surrounding pressure from the liquid because it must also counter the inward force from the surface tension at the gas-water interface. The radius of curvature of the interface is determined by the ratio of the surface tension of the water and the difference between the two pressures.

The bubble growth begins as the water layer adjacent to the heated surface becomes superheated. Water at the interface evaporates into the gas in the pit, expanding its volume. The radius of curvature increases and the inward force due to the surface tension decreases. (Something similar happens as you blow up a spherical balloon. Initially the balloon has a small radius of curvature and the inward forces opposing expansion are large. When the radius of curvature is larger, those forces are smaller and it is easier to blow up the balloon further.)

Since the inward force on the gas pocket is smaller, the pressure difference between the inside of the pocket and the surrounding water is reduced. The reduced pressure persists as evaporation into the pocket brings the gas-water interface up to the lip of the pit. Additional evaporation of water and expansion of the pocket push the interface upward farther, but the bubble still does not leave the lip.

The bubble now reaches a critical point. Its upward expansion decreases the radius of curvature of the interface, thereby increasing the inward force due to surface tension. At the critical point the interface is at its smallest radius of curvature, and correspondingly the inward force from surface tension is at its strongest. At that stage the difference between the pressure inside the bubble and the pressure of the surrounding liquid is at its greatest.

Either one of two things can happen now. If the surrounding water is sufficiently superheated, evaporation continues at the interface. The bubble grows larger as the interface moves away from the lip of the pit. The radius of curvature increases, decreasing the inward force due to surface tension. The bubble continues to grow and may eventually detach from the heated surface, leaving behind a pocket of vapor that can serve as a nucleating agent for the next bubble.

Alternatively, the surrounding water may not be superheated enough to force vapor into the bubble poised at the lip of the pit. The bubble stops growing, at least until the water temperature is increased by additional heat influx. Just how superheated the water must be to drive a bubble through the critical point in its growth depends partly on the size of the pit. A bubble in a relatively large pit (say 10 micrometers in diameter) may not require much superheating to continue through its critical stage. A bubble in a small pit (say one micrometer in diameter) reaches its critical stage with a smaller radius of curvature and thus a higher internal pressure. The surrounding water must be heated even more to push the bubble through the critical stage. That is why the smaller rough spots on the heated surface participate in the nucleation of bubbles later than the larger spots.

My argument, however, ignores the fact that many of the rough spots are not conical. It also ignores the possibility that a pit may not trap any air. As water is poured into a pan a sheet of liquid advances over the pits. Whether or not the water completely fills a pit depends on two factors: the geometry of the pit and the angle of contact between the advancing sheet of water and the metal. The contact angle is governed by the surface tension of the water at the air-metal interface. If the angle is larger than the angle of the conical pit, the water reaches the far side of the pit before it reaches the bottom. It therefore traps air in the pit to serve as a nucleating site. Otherwise the pit is entirely cleared of air by the advancing water and cannot function as a nucleating site.

Although the stage of boiling marking the change from the formation of slugs and columns to the burnout phase of the transitional regime cannot be achieved on a kitchen stove, the physics underlying the change is curious. Why should boiling rather suddenly switch from its greatest rate of heat transfer to a rate so low that it endangers the container? The peak transfer rate is achieved only because of the successful creation of bubbles on the heated surface. The bubbles' upward motion after they detach continuously stirs cooler water down onto the heated surface, preventing it from rapidly increasing in temperature to a catastrophic point. As the boiling process approaches the stage of peak heat transfer a network of bubbles emerges on the heated surface. They detach quickly and ascend in columns or slugs. Gushes of cooler water descend.

The columns of ascending vapor form a pattern over the heated surface. The condition in which a lighter fluid (a vapor layer) underlies a heavier fluid (water) is referred to as a Rayleigh-Taylor instability. It forces the ascending columns of vapor into an approximately geometric pattern. The heat is still transferred effectively through the water in this stage, but as the bottom surface is heated further the ascending vapor columns must move faster in order to maintain the boiling regime. Eventually they move so fast that their vertical surfaces break down into waves in what is called the Helmholtz instability. Thereafter the transfer is less effective and the boiling process quickly reaches burnout as the heat influx at the bottom surface overloads the ability of the system to convey vapor to the top surface.

Water is not the only liquid heated or boiled in the kitchen. I have often had the dismaying experience of overheating a thick sauce. In haste I turn up the heat too much. Then I conclude that since the top surface is still cool, the bottom surface must be almost as cool. Suddenly huge bubbles gurgle to the top surface and splash sauce all over the top of the stove.

Jeffrey C. May of the Cambridge

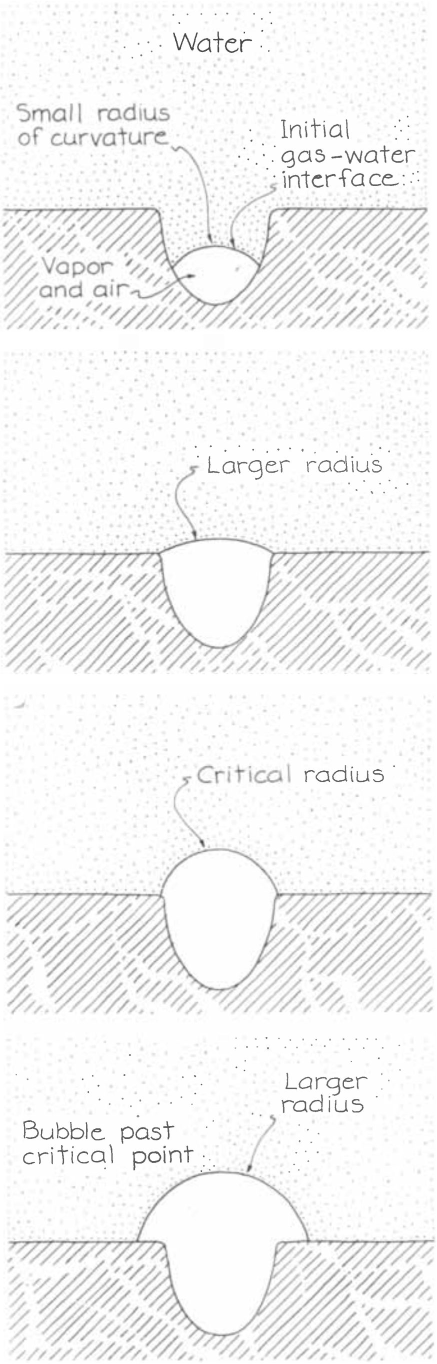
School in Weston, Mass., recently communicated with me about this common kitchen error. He shows that my mistake is in ignoring the viscosity of the fluid. In the early stage of heating water the normal convection of the liquid successfully conveys heat away from the bottom surface to the top, where the water can evaporate. In a viscous sauce the convection is ineffective. The sauce superheats at the bottom surface until large bubbles are generated. The top surface may still be cool. The bubbles suddenly break free from the bottom surface and rise to the top, where they burst vigorously.

In cooking pasta I have long followed two rules for boiling the water. The first is to heat an amount of water that is about three times the volume of the pasta. The reason is that with a smaller amount of water the nucleate boiling would be halted when the pasta was dropped into the pan and the transfer of heat would be limited to convection. The top of the water would cool, leaving the pasta in lukewarm water and complicating the cook's timing. When the pan contains the proper amount of water, the addition of the pasta scarcely affects the boiling process.

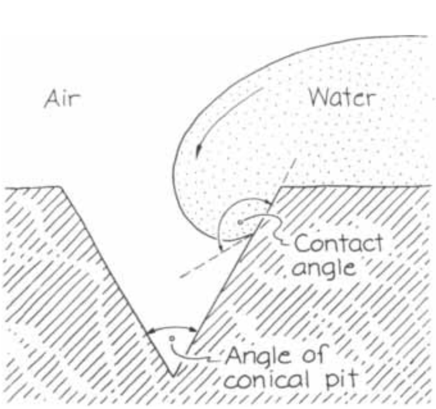
I have never been certain of the logic behind the second rule I follow. All recipes for pasta say to add salt. Surely the salt is for seasoning, but why should it be added to the pasta instead of to the sauce? It is asserted in explanation that the salt raises the boiling temperature of the water so that the pasta cooks faster. There is some truth to the assertion, because any solvent (here water) containing a nonvolatile solute (here salt) has a higher boiling point than the pure solvent.

In a rolling boil the vapor pressure from the water must match the ambient pressure on the water. When the water is unsaturated, the vapor pressure is lower than the ambient pressure. If a solute such as salt is added to the water, the vapor pressure of the water is reduced. The reason is that the presence of the salt (the ions of sodium and chloride) at the top surface makes the escape of water molecules from the surface less likely. When the solution of water and salt reaches what would have been the boiling temperature of pure water, the vapor pressure is still less than it would have been without the salt. The temperature increases further until finally the vapor pressure matches the ambient pressure. Then the solution boils.

Does the addition of salt speed the cooking of pasta? I added half a teaspoon of salt at a time to two quarts of boiling water. Although I doubled the amount of two teaspoons called for in a standard recipe, the water temperature rose by less than a degree. One must conclude that the salt serves only as a seasoning.



Stages in the growth of a bubble



How water flows over a conical pit

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(Signed) George S. Conn, Vice-President and Gen. Manager.

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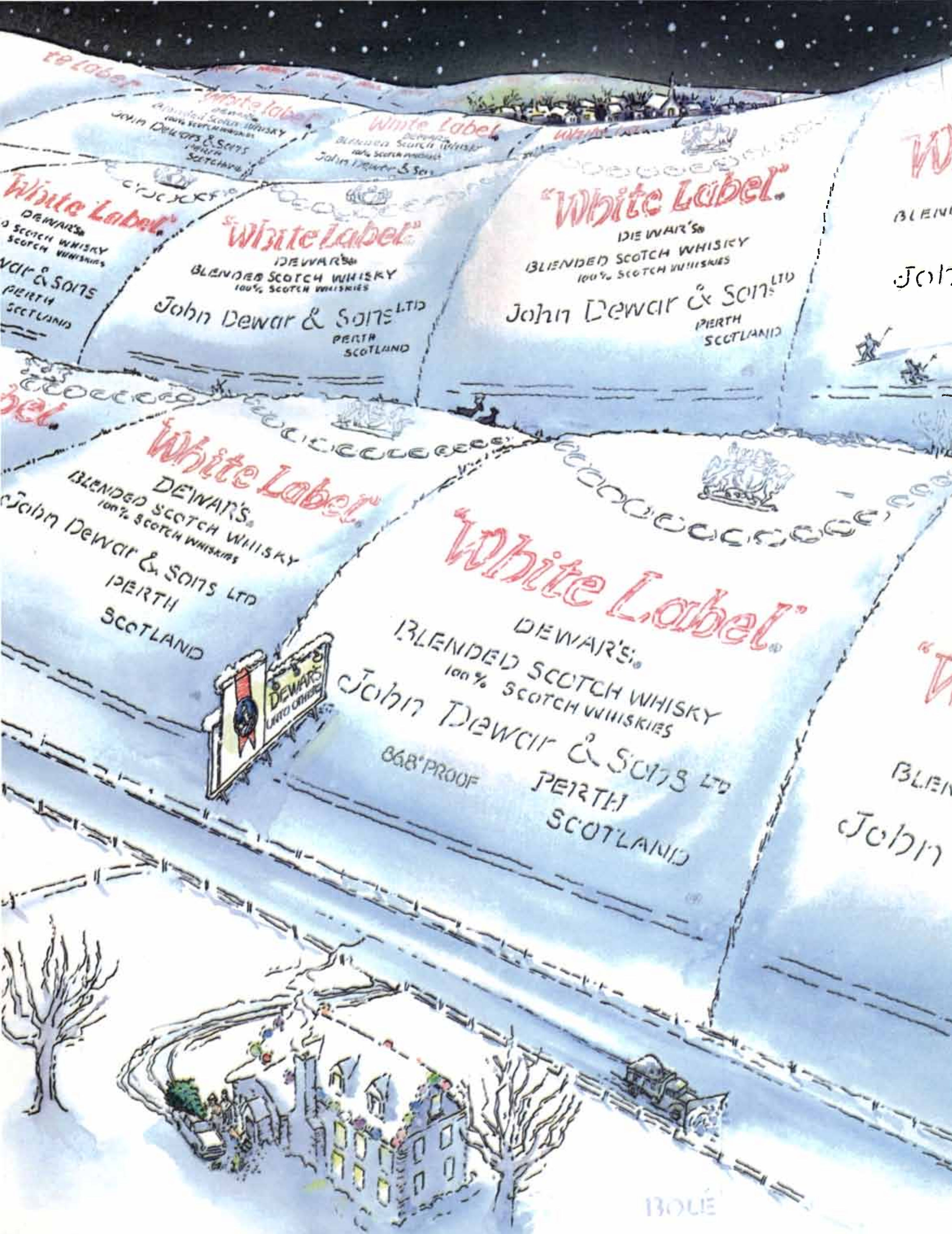
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