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AT&T'S JOHNSON EXAMINES THE SUPERCONDUCTING TAPE DEVELOPED WITH TEAM MEMBER BATLOGG

LAWRENCE BARNS

'OUR LIFE HAS CHANGED'

THE LIGHTBULB, THE TRANSISTOR—NOW THE SUPERCONDUCTOR REVOLUTION

With the poise of Harry Houdini, Bertram Batlogg reaches into his coat pocket. Slowly, he draws out a piece of flexible green tape and holds it aloft. There is silence. Then gasps and exclamations ripple through the crowd. "I think our life has changed," says Batlogg, who heads solid-state materials research at AT&T Bell Laboratories. The 3,500 physicists jamming the ballroom and surrounding hallways at the New York Hilton burst into shouts and applause.

The simple tape that Batlogg brandished at the annual meeting of the American Physical Society on Mar. 18 was indeed the pennant of a technological revolution. Because it can conduct electricity with no power losses to resistance, the tape material promises to have an enormous technological—and economic—impact. Such so-called superconductors could speed the way to a quantum leap in both electrical and electronic technology.

A torrent of developments is pointing to applications ranging from superfast computers to trains that float on magnetic fields, from less costly power generation and transmission to fusion energy. Although it may take 20 years before the full potential of these laboratory discoveries is realized, the economic impact could be enormous. Some scientists compare the importance of these advances in superconductors to the invention of the transistor. But to Jack S. Kilby, co-inventor of the integrated circuit, that's an understatement. "This is much broader," he says. "It could impact almost everything."

The normally staid physicists at the New York meeting apparently agreed. Like rock music fans waiting to get into a concert, the crowd began gathering for what they dubbed the "Woodstock of physics" 2½ hours ahead of time. When the doors opened for a hastily scheduled 7:30 p.m. session on superconductivity, scientists shoved and jostled each other for the 1,150 seats. The rest craned to

hear from the hallways or watched on video monitors outside. "I came to see history," declared one scientist as he elbowed his way to a seat. He wasn't disappointed. More than 50 researchers reported brand-new experimental results. Several revealed information phoned in from their laboratories just hours earlier. With only five minutes allotted to each, the session ran until 3 a.m.

The advances have been a long time coming. In 1911, Dutch scientist Heike Onnes first observed that some metals became superconductive when cooled to almost absolute zero—the point at which all motion of atoms ceases. That opened tantalizing prospects for huge markets. But the only way to get near that ultracold temperature of –459F—or zero on the Kelvin scale that scientists prefer—was cooling with costly liquid helium.

CHASING THE GRAIL. So the search began for materials that would exhibit superconductivity at warmer temperatures. The effort, however, was slow and discouraging. In 1941, scientists discovered alloys of niobium that became superconductive at 15K. By 1973 the best superconductor operated at 23K—warm enough to make a few applications, such as magnets for medical imaging, economical. But this was far from the physicists' Holy Grail of "room temperature" superconductors. Many despaired that such materials were even possible.

In just the last four months, however, researchers in the U.S., Europe, Japan, and China churned out a stunning set of discoveries. They created a group of materials that become superconductors at temperatures that can be achieved with inexpensive liquid nitrogen. That made frigid superconductors red-hot. "It's the most exciting development in physics for decades," declares Neil W. Ashcroft, director of the Laboratory of Atomic & Solid State Physics at Cornell University. "The pace of discoveries can hardly be matched." And the dream of room-temperature materials is no longer unthinkable. "We've knocked down barriers and removed our blinders about what's possible," says Paul A. Fleury, director of the physical research lab at AT&T Bell Labs.

No one, least of all K. Alex Müller, a physicist from International Business Machines Corp.'s Zurich research laboratories, expected the barriers to higher-temperature superconductors to tumble so quickly. It was Müller who set off the current research rush a little more than a year ago with the discovery of a superconducting oxide of copper. Hunched in a chair during a lull in the New York meeting, the 59-year-old Müller seems ill at ease with the attention he is getting. "It was so unexpected," he says quietly, stroking his beard.

Müller holds the prestigious post of IBM Fellow, which frees the company's distinguished scientists to pursue projects of their own choosing. With the freedom to explore, Müller took a cue from research in the U.S. and France to examine a little-known group of oxides containing copper and nickel. Normally insulators, the materials had displayed some intriguing metallic properties. So for nearly three years, Müller and his colleague, J. Georg Bednorz, mixed hundreds of compounds and tested them for signs of superconductivity. In January, 1986, they measured superconductivity at a record-breaking 30K in an oxide containing lanthanum, barium, and copper. Müller, who expected a rise of several degrees at best, was incredulous.

Bednorz, a former student of Müller's, was so excited he wanted to report the results immediately. But Müller refused. The history of superconductor research is littered with unsubstantiated claims and the tarnished reputations of the scientists who made them. Fearful that his peers would denounce the results, he insisted on additional tests. "I didn't want to ridiculize myself," he recalls.

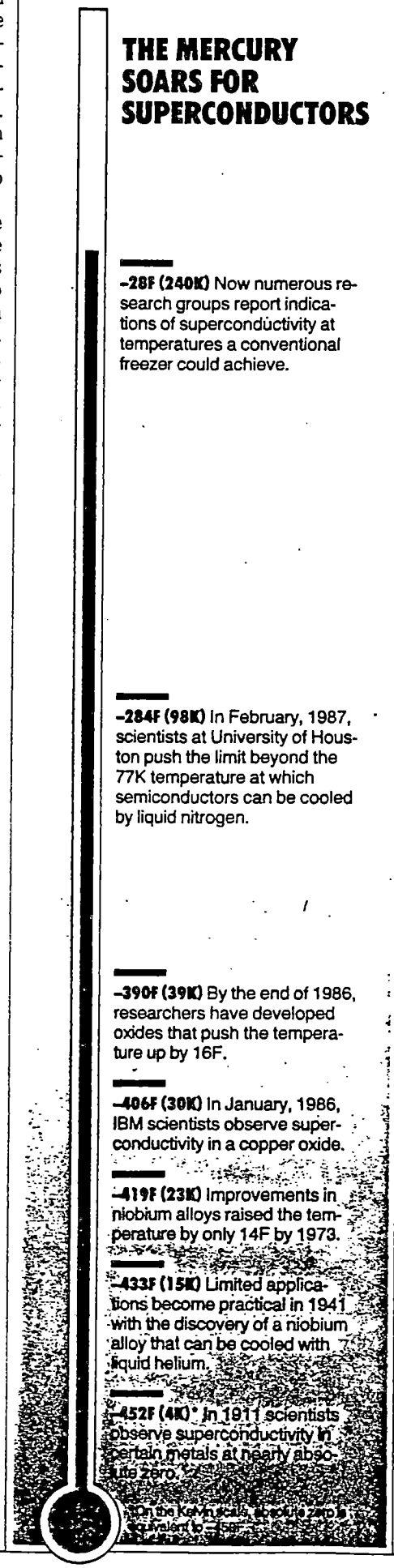
Only after they had confirmed their findings did Müller and Bednorz publish a paper. And then many U.S. scientists missed the paper when it was published last April because Müller chose a German journal not widely read in the U.S. Some who did read it doubted the findings. "I just couldn't take the claims seriously," says one physicist who now regrets his skepticism.

THE COLD RUSH. By fall, however, a handful of research teams was experimenting with Müller's compound. In December, reports discussed at a Boston scientific meeting created a sensation. Müller's work had been confirmed by a Tokyo University research team led by Shoji Tanaka and another group at the University of Houston headed by physics professor Ching-Wu "Paul" Chu. Immediately, scientists at more than a dozen labs, including AT&T, Argonne National Laboratory, and the University of California at Berkeley, began experiments on the substance.

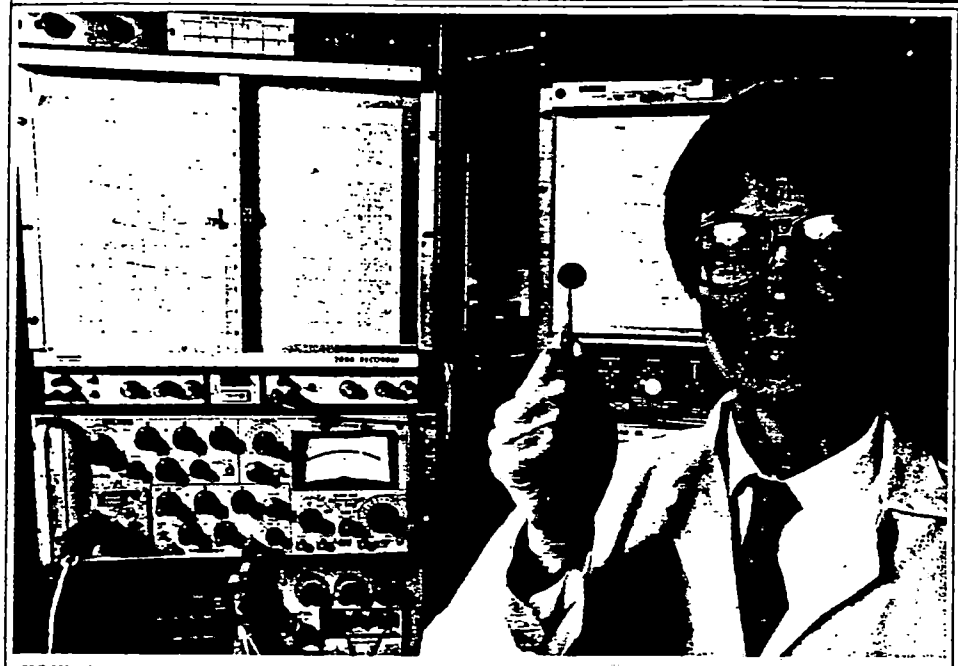
It was easy to jump on the research bandwagon: The promising oxides can be whipped up in the chemistry lab of any junior college. Simply grind the chemicals with a mortar and pestle and heat them in a furnace. Regrind the result, press it into pellets, and heat it again with oxygen. So by the end of December, researchers at AT&T, the University of Tokyo, the Institute of Physics, Academia Sinica in Beijing, and the University of Houston announced they had cooked up oxides that smashed Müller's record.

The scientists have been at it ever since. Chu and his close-knit team of six pushed the temperature of Müller's ox-

THE MERCURY SOARS FOR SUPERCONDUCTORS



ROB BOYLE/BW



YOU'RE GETTING WARMER: THE UNIVERSITY OF HOUSTON'S CHU WITH SUPERCONDUCTOR

ide to 52.2K. "But I knew we wouldn't go higher unless we found a new material," Chu says.

So he decided to substitute another element, called yttrium, for the lanthanum in Müller's oxide. Working with University of Alabama scientists under Wu-Maw Kuen, the researchers soon recorded signs of superconductivity at a torrid 100K in that oxide. "But we came back the next day, and it had disappeared," recalls the 45-year-old Chu. The researchers began an intense cat-and-mouse game with the material, trying to stabilize the superconducting properties at that high temperature.

The team tested dozens of recipes with little success, but Chu's optimism never flagged. "He always looks on the bright side," says Pei-Herng Hor, one of his Taiwanese-born colleagues. By early February the team scored: The researchers found a stable compound that was superconductive at 98K, well above the temperature at which inexpensive liquid nitrogen could be used for cooling.

'SCIENCE SUPERSTAR.' Chu kept mum for two weeks, but rumors quickly lifted the veil of secrecy. Researchers at IBM, AT&T, and the University of California at Berkeley immediately set out to discover the secret ingredient. "Chu ran the four-minute mile in superconductivity," declares James E. Shirber, manager of solid-state physics at Sandia National Laboratory. "He broke the barrier to liquid nitrogen." When the news got out, Chu earned the nickname "Science Superstar" from his staff.

That could prove to be an elusive title. Within weeks Tanaka, Z. X. Zhao from the Institute of Physics in Beijing, AT&T, and IBM were pacing Chu. By substituting still other elements such as calcium and lutetium, they concocted a dozen different oxides that become superconductors above 90K.

With so many teams after the ultimate superconductor and the prizes it might bring—perhaps even a Nobel—the tension among key researchers is becoming almost palpable. At the Physical Society meeting in New York, the scientists assiduously noted the dates when they observed high temperatures, developed compounds, or completed other ground-breaking work. "Everyone is writing history to make themselves look better," observes one physicist.



IBM'S K. ALEX MÜLLER: HIS DISCOVERIES A YEAR AGO KICKED OFF THE RESEARCH FRENZY

At a press conference during the meeting, Tanaka claimed the Japanese were first to experiment on certain compounds. Chu jumped up to add that his lab, too, was working on the same compounds at that date. Such incidents are "just the tip of the iceberg," says Chu. Although Chu and Tanaka used to compare work, the communication stopped once Chu began experiments on yttrium.

"It's frantic, mass hysteria," says Paul M. Grant, manager of magnetism and collective phenomena at IBM's Almaden Research Center in San Jose, Calif. "Everyone's exhausted." Grant, whose weeks of midnight research sessions resulted in the identification of the structure of one of the oxides, has the dark circles under his eyes to prove it. And the research is progressing so rapidly that it has outstripped the usual channels of scientific communication. At *Physical Review Letters*, the leading physics journal, more than 50 superconducting research papers await publication. "'Recently' in this field now means two days ago," says M. Brian Maple, professor of physics at the University of California at San Diego.

GETTING PRACTICAL. The race to push superconducting materials out of the lab has barely begun, however. Just because a substance loses its electrical resistance when it's dipped in a cold, liquefied gas does not mean it will be much good in the real world. To be practical, superconductors have to be fashioned into wires, cores of magnets, and the thin coatings that form the foundation of computer circuits. And the materials, which are basically ceramics, are brittle—and fragile. "It is a long road between discovery and use of the devices," says Robert J. Cava, a chemist at Bell Labs.

But scientists already are pulling off the basic developments that lay the foundation for commercial applications. One key finding is that the materials may make possible the most powerful electromagnets ever built. Tests at Westinghouse and AT&T indicate that the new superconductors can withstand magnetic fields up to 10 times greater than those possible with such materials as niobium. That could open the way to such applications as tiny but extremely powerful electrical motors and higher-resolution medical imaging machines.

By March, both IBM and Stanford University had used techniques common in the semiconductor industry to produce a superconducting thin film that could be used in computers. At Stanford, Theodore H. Geballe, a professor of applied physics, fashioned a film into a prototype device that might be an ultrahigh-speed data pathway between computer

(TOP) CONNOR/PRINCETON GROUP; (BOTTOM) WALTER P. CALAHAN

chips. An AT&T team that included Bertram Batlogg and ceramist David Johnson used ceramic processing technology to make its tape and small donut-shaped magnets. Japan's Fujikura Ltd. and Sumitomo Electric Industries Ltd. have made prototype superconducting wires.

The prospect of high-temperature superconductors shooting out of the laboratory has scientists lusting nearly as much after potential profits as scientific prizes. Just as semiconductor technology created Silicon Valley, the new superconductors may well create an "Oxide Valley." Already, some researchers are talking about starting companies. And Henry Kolm, who left Massachusetts Insititute of Technology to found a company to develop superconductivity applications a decade ago, believes the new oxides will open the door to venture capital. "People didn't consider helium practical," he says. Liquid nitrogen cooling, however, "is not far from frozen-food technology."

But just who owns the rights to the new technology promises to be a major muddle. The U.S. Patent Office is already sifting through dozens of applications on everything from the structure of oxides to manufacturing processes and devices. IBM and AT&T both contend they have claims for broad patent protection, but "it may be some time before we find out who has what rights," admits George Indig, a patent attorney at AT&T. Observers are predicting messy shootouts in the courts.

The rush of discoveries also leaves physicists with some loose ends. For one thing, they can't fully explain why the oxides are such superior superconductors. "It may be several years before we know what's going on, but there may be no theoretical limit to how high the temperature can go," says Robert Schreiffer, a professor at the University of California at Santa Barbara who won a Nobel for developing a theory of superconductivity. Indeed, by the time the New York meeting broke up, labs in the U.S. and Europe had reported signs of superconductivity well above 100K.

Such reports are spurring a frenzy of activity in Chu's Houston laboratory. Shoes are scattered under desks, and jackets and shirts are hung in corners, as the researchers work around the clock. The full-sized refrigerator is crammed with Chinese take-out food. "When you are No. 1, you always have to work to keep it," says Hor. "You hardly sleep." And Chu has his sights clearly on another record—125K. By mid-March rumors were circulating that he might be close. "Will history repeat itself? Who can tell," says Chu grinning.

By Emily T. Smith in New York, with Jo Ellen Davis in Houston and bureau reports

THE U.S. HAS THE ADVANCES, BUT JAPAN MAY HAVE THE ADVANTAGE

When a Houston laboratory announced a major advance in superconductivity research in February, Japan Inc. wasted no time. Its Ministry of International Trade & Industry immediately began assembling a consortium of government, industry, and university researchers. A MITI official describes the ministry's goal with missionary zeal: to exploit the "fantastic world of future industries" promised by new materials that conduct electricity with virtually no loss of power.

Both leading U.S. universities and major industrial companies such as International Business Machines Corp. and American Telephone & Telegraph Co. are playing a pioneering role in the spectacular scientific advances. But some experts fear that the Japanese ability to organize their research into a program with strong commercial goals could give them the edge in moving the research out of the laboratory.

At the moment, declaring a winner in the superconductivity race is premature. But leaders of the nation's science Establishment marvel at the speed of MITI's action. "I wouldn't call what they have done ominous, but it certainly is a sign of intensifying aggressiveness," says Roland W. Schmitt, General Electric Co.'s chief scientist and chairman of the National Science Board. Adds Carl H. Rosner, president of Intermagnetics General Corp.: "The Japanese have long recognized the tremendous potential of superconductivity, whereas the people in this country have been very shortsighted."

HEAD-SCRATCHING. No one government agency coordinates U.S. attempts to exploit the new science. Nor does anyone know precisely how much the U.S. spends on superconductivity research. But the National Science Foundation, which funded much of the recent U.S. research, estimates that federal agencies are funneling at least $8 million a year to universities.

American scientists and industrialists share the assumption that, as in the past, the U.S. system doesn't need a push from the government to bring innovative technologies to market. "The discoveries have been so spectacular that the level of activity is enormous in every laboratory in the U.S. with any capability in superconductivity," argues Schmitt. And Frank Press, president of the National Academy of Sciences, notes that a surprising amount of the academic work is aimed at applications of the new knowledge, such as thin superconducting films for computer chips.

But not everyone is satisfied. Ching-Wu "Paul" Chu, the University of Houston physicist who is the leading U.S. superconductivity researcher at the moment, thinks more action is needed to meet the combined weight of Japan's governmental, financial, and industrial resources. "We cannot afford not to move the same way as the Japanese," he says. "We really have to have a coordinated effort this time." In between those standing pat and the activists, there are a lot of people just scratching their heads. "Maybe," says one official half-jokingly, "what we ought to do is have some kind of conference to see what we ought to do."

'FIRST WIDGET.' But one aggressive government science administrator is not waiting. James A. Ionson, the astrophysicist who heads the Office of Innovative Science & Technology for the Pentagon's Strategic Defense Initiative Organization, is already busy forming his own consortium. He has lined up an unnamed university, a federal research laboratory, and a handful of small companies. Ionson's consortium will have a specific target: vastly improved space-based infrared sensors for detecting enemy missiles. "My concern is that if we don't pull the science into a technology fast, we're going to be beaten to the punch," says Ionson. "I think we've got to build the first widget."

Early proof that the science can be converted into a product might, as Ionson hopes, be enough to spur vigorous development. But there are no guarantees. Even in the basic science, the international competiton is fierce, and other nations are already scrambling hard for products because the potential payoffs appear to be so great. Furthermore, there are signs that the time from discovery to application may be exceptionally short.

Superconductivity is likely to be a severe test of the highly individualistic American system. Even as basic findings are still pouring out of the laboratories, the stark reality of the competitive marketplace looms. And Ionson's embryonic consortium is no match for MITI's directed Japanese effort. In this case, the U.S. may have to consider imitating Japan for a change.

By Evert Clark in Washington

THE NEW WORLD OF SUPERCONDUCTIVITY

Technologies and products once only dreamed of are suddenly coming within reach

Inexhaustible, cheap energy from fusion, desktop computers as powerful as today's number-crunchers, trains that fly above their rails at airplane speeds—all suddenly have taken a giant step closer to reality. But while scientists developing a new breed of "warm" superconductors are planting the seeds of an almost Utopian tomorrow, it will be up to engineers to reap the harvest.

That won't happen overnight. The novel materials that researchers are churning out in laboratories still have to be transferred to the factory floor. Significant hurdles must be cleared before an experimental circuit for a superconducting computer can be turned into mass-produced chips. A small sample of wire is a long way from cables that will span the nation.

Even in the fleet-footed electronics business, it will probably be 1990 before full-fledged products show up. For electrical utilities, it could take 10 to 20 years before the revolutionary new superconductors make a meaningful impact on power distribution. The challenge of scaling up lab results "could be formidable," cautions Paul M. Grant, manager of magnetics research for International Business Machines Corp.

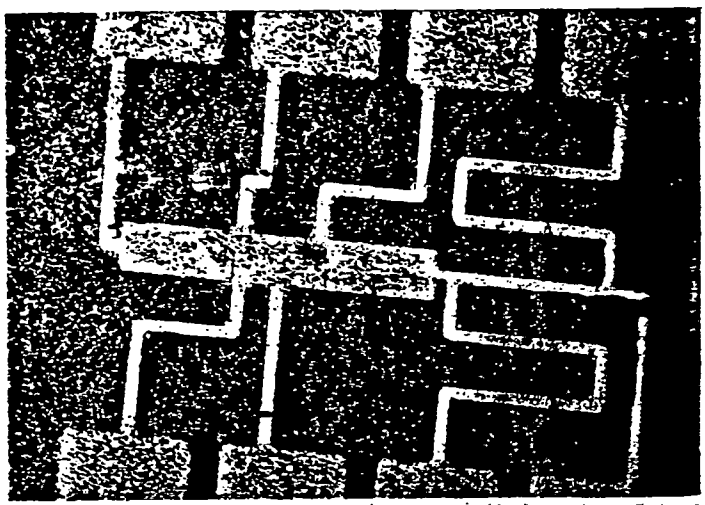
SCOTCH AND WATER. Until now, superconductivity has been limited to a few applications because the materials available had to be cooled to extraordinarily frigid temperatures with expensive liquid helium. "Liquid helium costs about the same as Scotch," says Walter L. Robb, senior vice-president for corporate research and development at General Electric Co. Liquid nitrogen is 10% as costly—roughly on a par with bottled water. And even with complicated and very expensive insulation systems, liquid helium escapes far more rapidly than liquid nitrogen, which can be protected with simple plastic-foam insulation.

The idea that it may soon be economically feasible to put superconductivity to work in myriad uses is sparking development projects at hundreds of companies worldwide. The payoffs would be enormous. And if room-temperature superconductors are ultimately discovered, the world could be transformed. Such "hot" materials could provide new tools for every technology related to electricity. But just the prospect of superconductivity at liquid-nitrogen temperatures is enough to excite most industrial engineers.

Practical nitrogen-cooled superconductors could save the utilities billions—

FOUR TECHNOLOGIES THAT WILL BE





POWER SYSTEMS If electricity can be transmitted vast distances without loss, the country's electrical demands could be met by burning less fuel. As it is, copper wires waste enough power to light up the West Coast. Power plants will become more efficient by using generators made with superconducting electromagnets. And giant electromagnets could even be used to store electricity for use during peak hours. Smaller and more powerful superconducting electric motors will cut industrial power bills.

ELECTRONICS Nothing since the transistor promises to overhaul computer science as drastically as superconductivity. The experimental microcircuit above, produced by International Business Machines Corp., heralds the dawn of a new age in electronics. Tomorrow's electronic systems will pack 100 or more times as much information-crunching power in smaller boxes. With powerful magnets and more sensitive detectors, medical imaging systems will give doctors dramatically sharper pictures.

(LEFT TO RIGHT) TOM WELLS/IMAGE BANK; SUPP SEITZ, CHARLES HILLMAN/BLACK STAR

and save enough energy to put 50 or more power plants in mothballs. Copper wires may be the conductor of choice now, but they lose a lot of power. The copper soaks up 5% to 15% of the electricity flowing through long-haul transmission lines, and still more disappears in local distribution lines. For Pacific Gas & Electric Co., these losses amount to $200 million a year—"plenty of incentive to use a new conductor," says Virgil G. Rose, PG&E's vice-president for operations.

With so much at stake, there has been interest in developing transmission lines and power generators even with existing superconducting technology. Research began in the late 1960s but eventually ground to a halt as the energy crisis faded and the cost of cooling with liquid helium stayed stubbornly high. One line was actually built in the U. S., a 300-ft.-long test installation at Brookhaven National Laboratory. It showed that the technology could not compete with a conventional system unless all the power needs of a city were fed through one line to minimize cooling costs, says Carl H. Rosner, president of Intermagnetics General Corp. But because of the inherent unreliability of such a system, no city would dream of putting all of its watts into one cable. If the new superconducting carriers can be fashioned into cable that can stand up to high power loads and alternating current, 10 or 12 "feeder" lines might be affordable.

Interest in using powerful superconducting magnets to build high-speed trains that levitate above their tracks has also flagged in the U. S., because of high capital costs. That interest, too, could be reviving. But the eventual builders of these so-called maglev trains are more likely to be in either West Germany or Japan, which have continued to fund serious research, or Canada, which still supports a modest effort.

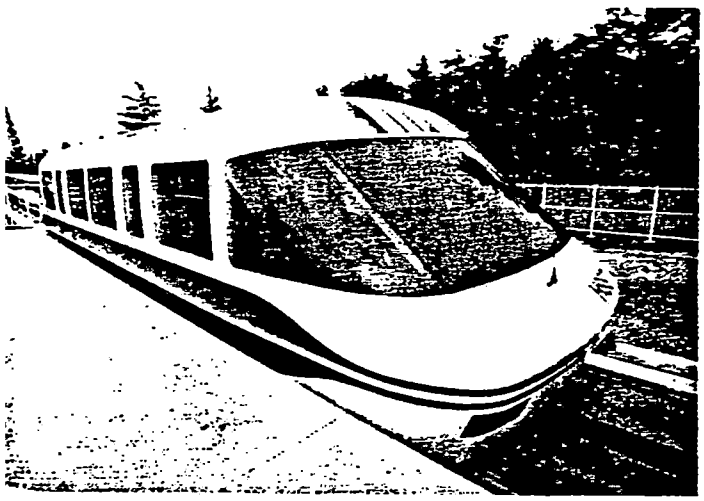
William F. Hayes, a senior research officer with Canada's National Research Council and a maglev believer, bubbles over with anticipation. The new superconductors will have "a tremendous impact on maglev," says Hayes. "The major problems were refrigerating units and reliability. All that's eliminated now." And trains aren't the only vehicles that could benefit. Hayes predicts that superconducting motors one-half to one-third the size of normal motors will one day power ships. They could also help eliminate urban air pollution by making electric cars practical.

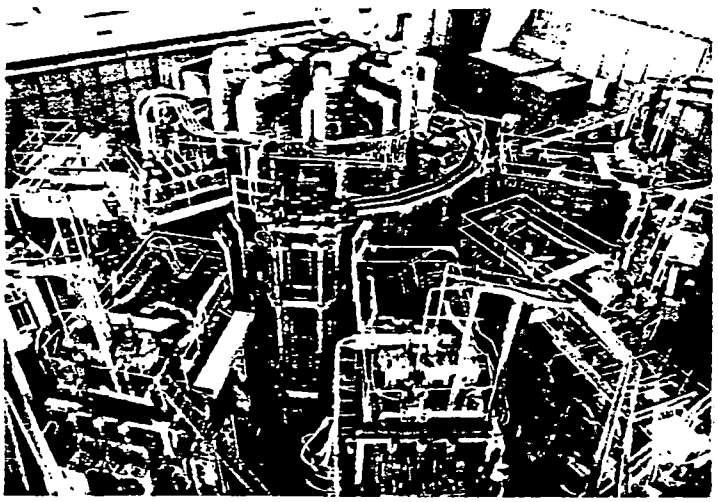
America's best shot at exploiting the new technology is probably in electronics. There, superconductivity will usher in what Sadeg M. Faris calls "the third age of electronics," after vacuum tubes and transistors. Faris worked on superconducting microchip devices known as Josephson junctions at IBM. When Big Blue decided in 1983, after 14 years of work, that the technology was a no-go, Faris left and founded Hypres Inc. In February, less than four years later, Hypres unveiled the first system based on Josephson junctions. Now, Faris asserts that Hypres will be the first to build chips using the new materials, because "no one else in the world has a manufacturing line producing JJ chips."

SUPERCHIPS. That distinction isn't likely to last long. Major electronics companies, from IBM to Varian Associates, are racing to explore the new superconductors. "Guys are working like maniacs," says John K. Hulm, director of corporate research at Westinghouse Electric Corp. "I haven't seen anything like this in years." Westinghouse wants to use Josephson junctions, which are up to 1,000 times faster than conventional silicon transistors, to build radar systems it believes would outperform any now available. At Varian, a leading maker of equipment used in semiconductor fabrication, a crash effort is under way to verify the work on superconducting thin films being done at nearby Stanford University. Such films could be the starting point for tomorrow's superchips.

Health care is another area where su-

THE FIRST TO FEEL THE IMPACT





TRANSPORTATION "Flying" trains should get a big lift from inexpensive and lightweight superconducting magnets and motors. So-called magnetic levitation systems, such as the experimental Japanese train above, use powerful magnetic fields to lift the entire train off the track, so it floats on a cushion of air as it rushes along at speeds of up to 300 mph. That's twice as fast as Japan's famous "bullet trains." Smaller, more efficient superconducting motors could power ships and electric cars.

SCIENCE In their never-ending quest for knowledge, physicists want to smash atomic particles into smaller smithereens or, conversely, to fuse atoms together and mimic the energy-generating furnace inside the sun. To "bottle" an ultrahot fusion reaction in a so-called tokamak device such as this one at Princeton University, magnets more powerful than any now available will be needed. Magnets made with the new materials could also boost the power of future atom-smashers.

perconductors could have an early impact. Nuclear magnetic resonance (NMR) scanners rely on powerful superconducting magnets to produce unprecedented views of the body's organs. The new materials promise magnets 10 times more powerful than those now used. And if NMR machines shed the cost and bulk associated with their present cooling systems for helium, the market for them could be a lot bigger. "You could site NMRs in smaller hospitals, even clinics," says Dr. Paul Winson, director of business development at Britain's Oxford Instruments Group PLC, the leading supplier of NMR magnets. Diasonics Inc., which has sold more than 100 NMR scanners, estimates that cooling with liquid nitrogen might save $100,000 per year in operating costs per machine.

The new superconducting materials may also produce magnets that give theoretical physicists a closer look inside atomic particles. Just eliminating the helium needed to cool the 10,000 giant magnets in the proposed superconducting supercollider would lop $160 million off the projected $4.4 billion cost of the atom smasher—plus cut energy usage by 25%. Researchers argue that waiting for the ability to eliminate helium should not hold back the project, which earned a green light from the President early this year, but they say the possibility of replacing those magnets should be kept open. "We could use them to upgrade the energy of the instrument four or fivefold," says Stanley G. Wojcicki, deputy director of the project. "That would give you a tremendous increase in scientific reach."

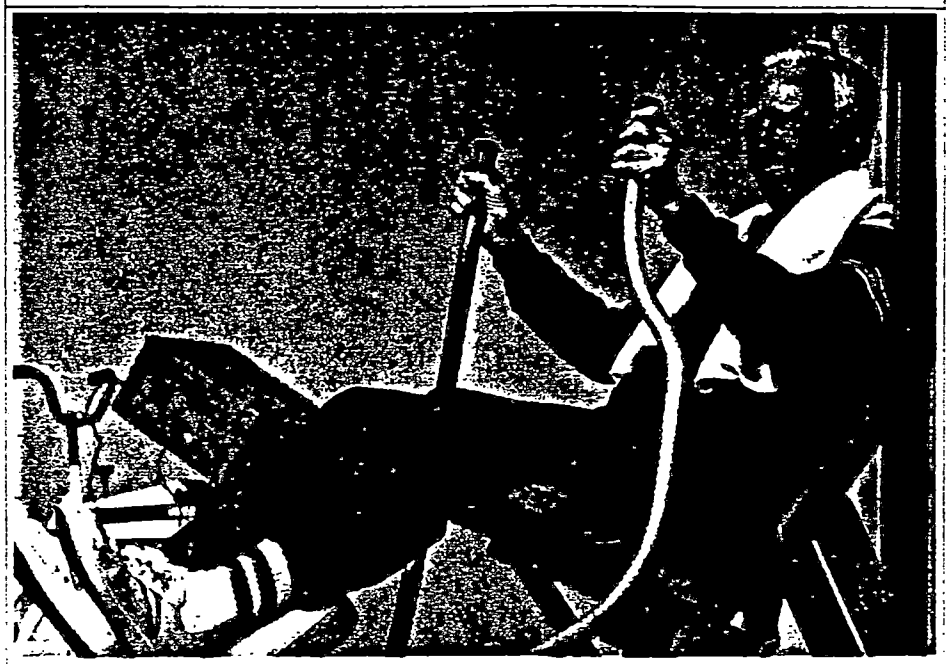
Ultimately, physicists hope the new superconductors will hold the key to practical nuclear fusion. Such reactors need powerful magnets to contain the intense heat of the reaction, which will be even hotter than the sun. The U. S. magnetic fusion effort has been trimmed by 20% since 1985, to $345 million this year, and Princeton University's Plasma Physics Laboratory, the site of the major U. S. fusion project, is being outspent by rival projects in Europe and Japan. The new superconductors, hopes Robert M. Hill, a senior scientist at SRI International, could revive fusion's prospects.

They may even boost Star Wars. The Strategic Defense Initiative Organization's Office of Innovative Science & Technology has already marked $500,000 for superconductor research this year and plans to buck it to $2 million next year. The interest is easy to fathom. After all, space-borne systems built with superconductors wouldn't have to be cooled: In space, "room temperature" is even colder than liquid nitrogen.

By John W. Wilson in San Francisco and Otis Port in New York, with bureau reports

CAN GTE KEEP FOILING THE RAIDERS?

It's retrenching, building defenses, and hunting for prey



CHAIRMAN BROPHY: ANALYSTS SAY GTE'S STOCK IS STILL UNDERVALUED

How much restructuring is enough? For Theodore F. Brophy, chairman and chief executive of GTE Corp., sales or joint ventures of operations accounting for 10% of annual revenues is plenty. But Wall Street, which is still hunting for undervalued breakup candidates, is giving Brophy no respite. Despite a protective thicket of regulators, asset-rich and underleveraged phone companies such as GTE are no longer immune. The Bell System breakup proved their pieces are worth more than the whole. So, the steel-willed, patrician Brophy is being challenged to boost shareholder values.

That pressure escalated last fall, when Canada's Belzberg family bought a less-than-5% stake in $15 billion GTE and called for its partial breakup. Brophy checked the threat by winning shareholder approval in December to stagger the elections of directors and adopt an 80% voting rule on takeovers. GTE also split its shares 3 for 2, boosted the dividend 13%, and began a 3% stock buyback. That pushed its shares up 23%, to a less vulnerable $43. As for more restructuring, says Brophy: "You can improve net income for a time [with more leverage]. But I don't believe you're making any contribution to the future."

Brophy's problem is that while he has hiked GTE's total stock-market worth to almost $14 billion, some Wall Street analysts say that is still barely half the company's breakup value. And just over the horizon are some fundamental changes in the phone business that could make a breakup more possible.

CABLE EXPERIMENT. One is deregulation. Already 13 states have stopped regulating phone profits based on assets and equity invested. Now they let companies earn whatever they can—so long as they hold down rates and maintain good service. Under previous "rate-base" regulation, a phone company buyer could earn money only on the depreciated historical cost, or book value, of the assets acquired. With deregulation, a buyer could pay more than book value and still reap a good return on equity if he could cut costs or boost revenues.

A second factor is new technology. By the early 1990s, customers will have access to a basketful of voice, video, and data services over telephone lines. Many of these will be unregulated. Whoever owns the computerized phone network

Ringing in the Future by Changing the Past

SUMMARY: The video-fax-phone of "Back to the Future Part II" is from 2015. But its availability could be fewer years away — or so claim the Bell telephone companies, which charge that regulations in the 1984 AT&T breakup have prevented them from entering the future of telecommunications. An appeal of the consent decree is being heard. A decision favorable to the Bells may hang on whether the court sees the firms as having a First Amendment right to distribute information.

BASED ON PHOTOS BY RICHARD KOZAK AND JANICE RUBIN

Steven Spielberg's latest box office blockbuster, "Back to the Future Part II," proffers a high-tech vision of home life in 2015. Dominating the tacky living room furnishings and looking like video wallpaper (which rolls up and out of sight like a window shade) is the telephone. Apart from its striking video features, such as caller identification (address, occupation, politics . . .), this telephone differs from the humble household instrument of the 1990s in that, along with voice, it simultaneously transmits facsimile. And in turn this combination — voice, video and data (that's the fax) — leads from the future right back to the present.

"What you see in the movie is really no big reach on today's telecommunications technology," says Joseph Kraemer, head of the international telecommunications consulting group at the Big Six accounting firm Touche Ross. According to him, video-fax-phones are right around the technology corner. "Even the security device portrayed in the movie of using your thumbprint to get in and out of the door is used today in industrial applications."

Spielberg makes the future of telephony look like fun. But his cinematic creation manages to portray one subtle but very important here-and-now truth about the ubiquitous telephone: Today and in the future, it will form the glue for a raft of services: broadcast, cable and high-definition TV; facsimile, publishing, research, shopping, marketing, polling; electronic directories and mail; computing services; and so on.

The effect of being able to transmit all these services simultaneously will be to destroy time and distance, as H. G. Wells might have put it. That means that relatives or business acquaintances across the continent would not only appear on-screen when reached by phone (if they want to, that is) but also that documents, letters and photos could simultaneously be passed along by fax. It would be like handing papers through a mail slot. No waiting. No travel. Contracts could be signed and validated in video conferences by card-reading machines, similar to those in use today that verify credit card transactions.

In effect, the phone would create an office without walls, where contact and interaction, the camaraderie of the workplace, could go on among workers in widely separated locations. The Tokyo and New York offices would share one "wall" or "window," supplied by phone, through which workers could look in on one another. Time and distance might not go away, but they certainly would be rendered transparent.

For now, however, that future waits on hold, at least according to some of the key players — the Bell operating companies that were born with the consent decree that broke up the American Telephone & Telegraph Co. in 1984. The decree turned AT&T into a long-distance company and created seven regional companies, known as the Baby Bells, with 22 subsidiaries that handle local service. Since all calls, even long distance, must begin and end locally, the Baby Bells maintain a virtual monopoly on local service.

To protect and promote competition from this monopoly, the decree banned the Bells from three lines of business: information services (electronic shopping, for example), manufacturing (video telephones, say) and long distance. These restrictions, argue the Bell companies, keep them from providing the revolutionary services today's humdrum telephone is capable of offering.

While no one expects the Bell companies to be allowed back into long-distance service (at least until there is competition for local service), they have been scrabbling to get into information services and manufacturing. With these lines of business in their portfolios, they could use their financial clout and economies of scale — not to mention a telephone network that touches virtually every home in the nation — to drive the industry back into the future.

But other factors are also keeping the superphone on hold. Cost, for one, is hobbling the process of wholesale innovation, not just in terms of affordability but in terms of policy. It is virtually carved in stone that universal service will be the guiding principle of the U.S. telephone industry. "The problem for the phone companies," says Kraemer, "is how you get everything done in volume so that you can drive your unit cost down to get universality."

There is an even larger question of whether there will be a residential market for such superphones. Industry watchers say the public has shown little enthusiasm



JON A. REMBOLD / INSIGHT

Pearce: "Restrictions make no sense."



RICHARD KOZAK / INSIGHT

Judge **Harold H. Greene** of the U.S. District Court in Washington may be the only truly historical figure in the current debate over the Bell companies. Greene was in charge of writing the Civil Rights Act of 1964 and the Voting Rights Act of 1965, the most important civil rights legislation of the era. He presided over the consent decree that broke up the largest company in U.S. history, AT&T. With a Democrat in the White House, he would have been a candidate for the Supreme Court. As it is, he is one of the nation's preeminent judges.

His opinions are famous for detail and clarity. He says his aim in this is accessibility. "People should be able to understand what the courts are saying." He particularly avoids bureaucratese, which litters complicated issues like telecommunications.

"I am just a simple District Court judge," he says. It is something he often points out. "I merely carry out what the decree says. This has all been affirmed by the Supreme Court." In this he is perhaps too humble.

Fundamental to Greene's reading of the consent decree is the notion that only by regulating the Baby Bells' monopoly of local telephone service can competition sprout up and flourish. The decree pronounces competition as the greater good on this issue of communications. The irony for a great, unapologetic, liberal judge is that in supporting the line of business restrictions against the Bell companies, he is enforcing what he sees as a conservative principle: the unhindered promotion of competition.

"Businessmen who tout the advantage of competition, which is the whole capitalistic ethos, say, 'Well yeah, competition's not important in telecommunication.' I ask why is it important in department stores and not in communications?" ■

for the idea of high-tech telephony, as evidenced by the ho-hum reception for products currently being ramped up by the telephone companies — shopping services, caller identification, voice messaging. Says Tom Cohen, counsel to the Senate Commerce, Science and Transportation Committee, "No one is banging down the door for changes in their telephone service."

Of course, the public wasn't clamoring for Henry Ford in the days of the horse and buggy, either. And "in 1970 no one from the public was pounding on the door of the FCC asking for cable television," says Alan Pearce, then an economist at the Federal Communications Commission. "No one was screaming, 'I want my MTV.' "

Already, powerful forces are contesting for position in the prospective market. The American Newspaper Publishers Association, for one, opposes the Bell companies in their quest to publish information electronically. The publishers fear the companies could use their monopolistic grasp over the local telephone network to the detriment of the competition the publishers want to provide — namely, newspapers offering their own information services over phone lines. This would include sports phones or electronic classified advertising, the so-called audio and videotex services. The National Cable Television Association and the National Association of Broadcasters, both rich and powerful lobbies, side with the publishers. They fear that changes in phone regulations would let the Bell companies compete freely with (and to the disadvantage of) the TV industry.

Who wins the battle for this putatively vast and lucrative market will be decided either in Congress or in the courts, where, in recent months, a key court appeal and factional changes on the Hill suggest new action on the telecommunications horizon. In December the U.S. Court of Appeals for the District of Columbia Circuit began hearing oral arguments on an appeal that could have a powerful effect on the consent decree, freeing the Bells to provide information services such as electronic phone directories.

In January, as Congress reconvenes, telecommunications is said to be high on the agenda. Rep. Edward J. Markey, chairman of the Commerce and Science Subcommittee on Telecommunications and Finance, is upbeat about the chance for new legislation in the coming session. "It's going to be a very, very busy year," says the Massachusetts Democrat.

Also heating up the issue are personnel shifts on the regulatory front that augur well for policy changes in Congress. The rocky relations during the Reagan years between the Federal Communications Commission, the chief regulatory agency for the phone companies, and Congress are said to be on firmer footing because of changes in leadership. A new chairman, Alfred C. Sikes, has been installed at the FCC, and two new commissioners have taken up three of the four vacant posts on the commission, with the final appointment expected imminently from the tardy Bush administration.

Over at the Commerce Department's National Telecommunications and Information Administration, which advises the executive on regulatory policy, a new administrator, Janice Obuchowsky (former administrator Sikes having moved to the FCC), has promised an important new policy report on the nation's telecommunications infrastructure by early January.

These movements on the rules side, coupled with wrangling in the courts and pressure on Congress, have the financial community on alert. "The pressure is clearly there that you would look for something to break in the next 12 to 18 months," says Touche Ross's Kraemer. By that he means some change in the way the Bell companies are regulated, with Congress possibly legislating policy away from the courts.

Kraemer's firm recently surveyed 500 of the top business executives in the United States. Fully 86 percent favored turning the Bell companies loose from at least one antitrust constraint, that of information services, allowing them to compete in television and telephone — everything the newspaper publishers and TV interests fear. The firm gives the appellate court a better than even chance of allowing the Bells to offer such services.

Complicating everything are the raging economies of the telephone business. In the United States alone, the assets of the industry are valued at $242.3 billion. The industry employs 680,000 people. In 1989 its investment in new construction and equipment totaled $20 billion. Revenues exceeded a mind-boggling $89 billion. With 1.7 billion telephone conversations taking place each day, it is little wonder that the industry is constantly chafing.

The fact is, there has never been a major overhaul of the Communications Act of 1934, despite the revolution in technology



JANICE RUBIN FOR INSIGHT

Videotex user LeMay says, "I like the horoscope, biorhythms, things like that."

that has produced satellites, personal computers, videocassette recorders, digital technology, fiber-optic cable, high-definition TV, cellular telephones, mass information storage and answering machines.

A touchstone telecommunications report published in 1988 by the telecommunications and information administration, known as Telecom 2000, reflected this economic energy and declared: "As America progresses toward the 21st Century, the horizon offers vistas of matchless promise, potential and opportunities. New technologies, embodied in commercial innovation driven by the economic engine of competitive enterprise, can help satisfy our nation's critical needs in new ways. . . . Today *is* the 'Information Age,' and telecommunications comprises its chief transport system."

Bell Atlantic dittoed that optimism in a crystal ball-gazing booklet, "Delivering the Promise: A Vision of Tomorrow's Communications Consumer." The company fancied the telephone being transmuted into a video screen that "will be a combination of many products and technologies: TV; radio; stereo; video recorder and player; audio tape recorder; computer; high-speed graphic printer; facsimile machine."

Peggy LeMay, a 34-year-old bookkeeper in Houston, is among the first in the country to have a working view of the Information Age as projected by the movie industry, wished for by the Bell companies and promised in the Telecom 2000 report. She has a video terminal similar to a computer screen plugged into her telephone, a present-day precursor to the Spielbergian video wallpaper.

The little gray and black plastic unit supplied by Southwestern Bell Telephone, a wholly owned subsidiary of Southwestern Bell Corp., does not yet carry live full-motion video pictures, but it allows a user to send and receive data, even facsimiles. It is limited in that users cannot carry on telephone conversations while simultaneously sending faxes, but experiments taking place elsewhere around the country promise to remedy this.

As of August, the SourceLine system boasted 185 services for telephone users, among them: new business legislation reports; career counseling services; a direct line to the local Better Business Bureau, where a user may look up the records of more than 10,000 companies; stock market updates; a job-search list; film and TV reviews; a listing of day-care facilities; senior citizen services; a special section for French-language speakers; car clubs; information on local contractors; and recipes and wine information.

The terminal, which until December was the only one of its kind in service by a Bell company, is essentially a domestic version of the successful Minitel videotex terminal, which has been in use in France since 1986 and has more than 5 million users. French phone subscribers can get the terminals free on request. (Touche Ross, in its survey, found that many U.S. executives felt that the French phone system outperformed the U.S. system, which has long been the unofficial international standard for quality.)

LeMay, who says she spends $10 to $15 a month on SourceLine, uses it primarily for games and entertainment, as do most users. "I like the horoscope section," she says, "biorhythms, things like that." An avid newspaper reader, she does not bother with the system's news service. Recently, when she needed to consult a physician,

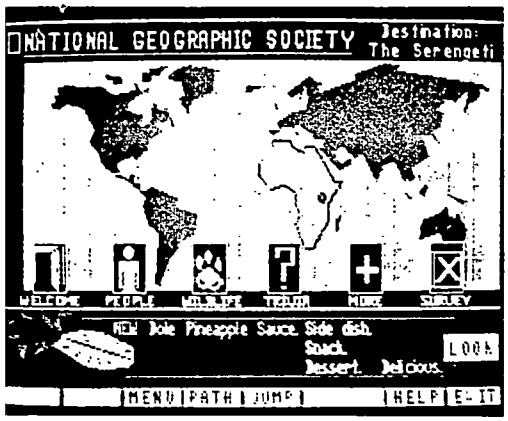


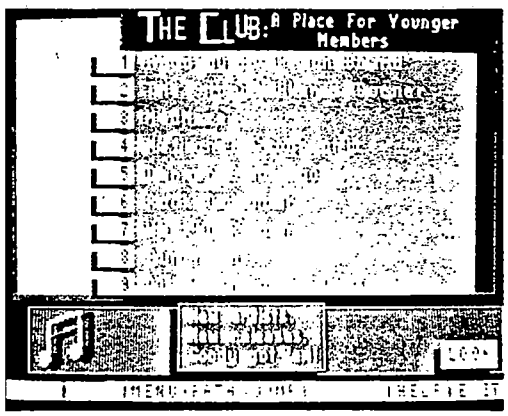
RICHARD KOZAK / INSIGHT

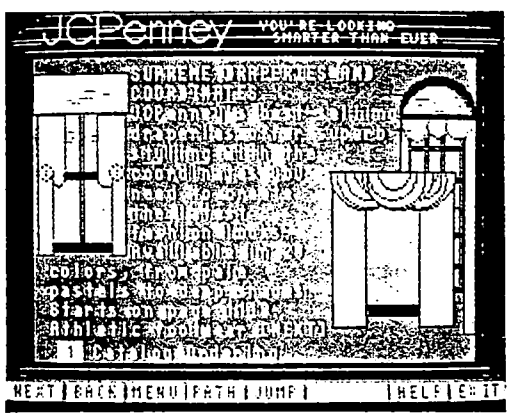
The soft-spoken chairman of the Federal Communications Commission, **Alfred C. Sikes**, is a technician with the heart of a visionary. He notes with real pleasure, for instance, that when his daughter registered for college recently, she was able to do so by telephone. "What I try to emphasize," he says, sounding very much the bureaucrat, "is that we have to be flexible. Telecommunications is a highly dynamic sector. Today satellites provide us with much of our telephony service. We've got multimedia used in a variety of circumstances. We're in a period where we're rapidly increasing data speed, rapidly developing audio."

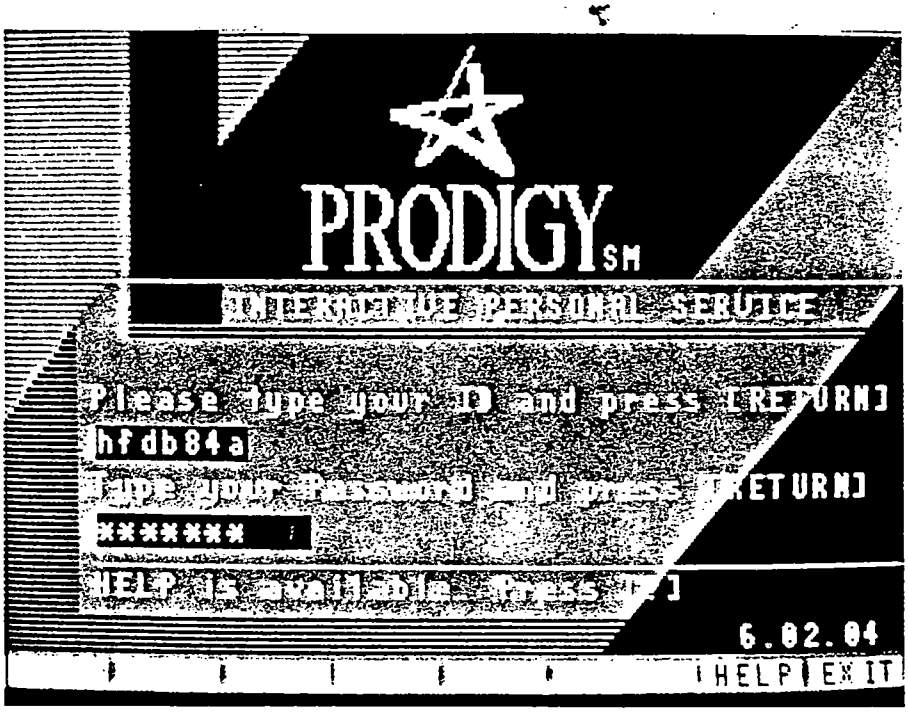
He is best known for the unusual notion with a commonplace ring: "video dial tone," a concept he promulgated as chief of the National Telecommunications and Information Administration. The idea is that someday the telephone and the television will merge into a single medium.

Until now, however, video dial tone has been just a buzzword. Sikes, at NTIA, was constrained to merely advocate his ideas (although at the very highest levels). At the FCC, things are different. Sikes makes and enforces the rules. If he can get along with Congress, he could have the power to direct the industry toward the vision of video dial tone. ■









Prodigy offers geographic data to young users — and home shopping for adults.

she was able to target one near her home through the service. But, she complains, "there were only four or five to choose from."

A self-described computer fanatic, LeMay thinks the system would be more successful if users could get information on the spur of the moment — a doctor, the day's horoscope. This is precisely what such services were conceived to do: to speed the user past the ballast of useless information that clutters the workaday world. But such services are far from living up to their promise. "The system is slow and time-consuming," she says. "If I need something fast, like where to go, what to do, what to see, I look elsewhere."

In a Yankelovich Clancy Schulman poll, 1,206 adults were asked whether they thought a terminal like the one used by LeMay would be an attractive item to own. Sixty-two percent replied no. There is a Luddite lurking in lots of people.

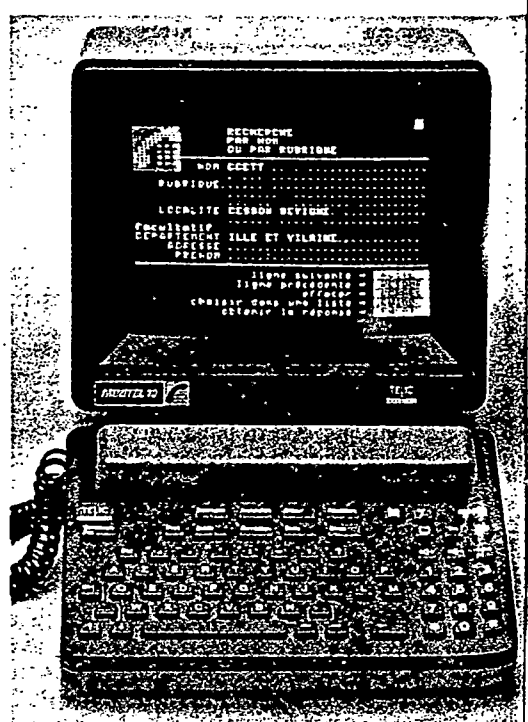
This isn't exactly good news to Southwestern Bell, but the company views its Houston experience as merely a trial run. Company officials seem content with its 16,500 subscribers (more than eight times the size of any similar Bell company service), 70 percent of whom use the terminal provided by Southwestern Bell (others use their home computers).

What distinguishes SourceLine from more established videotex services — such as CompuServe (489,000 subscribers, plus another 53,000 from its recent purchase of the Source), GEnie (135,654) and Delphi (about 60,000) — is that it is provided by a Bell company through what is known as a gateway. Gateways are often aptly compared with shopping malls. They provide the facilities for a variety of stores, in this case, information providers. The Academic American Encyclopedia, for example, is an information provider frequently found on gateway services such as SourceLine. A stay-at-home shopping service such as Comp-U-Store is another. The Bell companies do not actually provide the information on their gateways; they are prohibited from doing so by the consent decree. To use the analogy, the Bell companies may own the mall but not a store in the mall.

The Directory of On-Line Databases, which tracks such information services, totes up 75 gateways in service around the country. Only seven (counting Nynex Corp.'s promised Boston gateway) belong to Bell companies in the United States; they reach approximately 25,000 households. Bell Canada counts 24,000 households on its gateway.

Gary H. Arlen, publisher of the authoritative communications industry newsletter Interactivity Report, says the Bells' gateway services are not living up to expectations. "Southwestern Bell is doing better than most gateways because of its terminals," he says. The phone company gives terminals to users for a trial period of several months before charging monthly fees. That is when people begin signing off. Arlen estimates that 400 customers a month drop Southwestern's service, although he notes that at the same time it is growing at a not unpromising rate of 10 percent a year.

"The Bell company gateways would do better," Arlen says, "if they made a commitment to strong management. They don't have the personnel, and they don't promote



French Minitel boasts of 5 million users.

their products." An exception to the tentative approach to gateways taken by the Bell companies is Prodigy Services of White Plains, N.Y., a joint venture between Sears, Roebuck and Co. and International Business Machines Corp. It has widely promoted its services and spent heavily on a start-up that has been estimated to have cost an astronomical $250 million to $600 million. This, in the videotex industry, with total sales of only $113 million for all of 1988.

Prodigy is designed for use strictly on home computers, whose market is growing at 20 percent a year. After a $49.95 sign-up fee, which includes computer software and three months of free usage, Prodigy charges a monthly fee of $9.95.

Since its start-up in September 1988, Prodigy claims to have reached 160,000 households with more than 250,000 members (having grown 60 percent during the past three months). The service predicted early last spring (**Insight**, May 1) that it would be available in 20 markets by year's end; it had reached 22 by November. In the process, it has helped rescue the wheezing telebanking industry, signing on 13 financial services after institutions such as Chemical Banking Corp. threw in the towel on their own products.

Altogether, Prodigy offers a substantial list of 750 editorial features and 250 shopping information opportunities (compared with 185 on SourceLine). The Wall Street Journal's summer centennial issue named the Sears-IBM venture one of 66 companies "for the future."

"Where Prodigy may be running into problems is with its advertisers," says Arlen. The service depends on advertisements to make a profit, as well as to subsidize the monthly user fee, which must be kept low to make the service available to more users and thus more attractive to the advertisers. "They're getting more advertisers," maintains Arlen, "but it took them a long time to crawl through the 200-advertiser level." He thinks advertising has once again plateaued. "The issue is how much business the advertisers are doing. No one can prove that they're jumping for joy."

Arlen's tempered optimism for gateway-videotex stems from the product's discouraging history of flameouts. The Source, for instance, one of the first and most successful information services offered to the home computer audience, sputtered out in the mid-1980s, losing 37 percent of its subscribers, and got swallowed by CompuServe last June. So tough has the service been to sell to the public that two regional Bell companies have simply sidestepped the business.

Ameritech, the Great Lakes regional Bell, shows little interest in the gateway concept and says it prefers to take a wait-and-see approach. Pacific Telesis, the West Coast regional, simply dumped its gateway plans in October, complaining that court rulings were keeping it and its sister companies from providing the sort of smart, interactive product it thinks the public wants.

"It's all Kabuki," says Arlen, who believes that the Bell companies are using theatrics to make a point: namely, that given the right to sell information services, to own the stores as well as the mall, they could bring the marketplace to life. Fundamental to the mall concept, say the Bell companies, is the need for an "anchor" — a Macy's, Nordstrom or Neiman Marcus: one service that will attract customers to all the others.

In Bell operating company parlance, that means yellow pages. More specifically, electronic yellow pages, which allow for searches not only according to business — a plumber or electrician — but by location and special services. For example, by using an electronic yellow pages on a SourceLine-style terminal, users could request a list of only those plumbers who work in their neighborhood and are available for service 24 hours a day.

With the addition of an up-to-date classified advertising section, an electronic yellow pages would pose a real threat to newspapers ($12.5 billion, or 38 percent, of advertising revenue comes from classifieds), because users would not have to scan narrow columns of agate type, circling the items that interest them. They could make requests and the system would respond. When looking for a used car, for example, a user could request a listing of all 1987 Oldsmobiles that have low mileage, air-conditioning and a price below $8,000.

The phone companies say the electronic use of directories would provide them with the capital instrument necessary to install and subsidize the cost of terminals in every home. They cite the example of Minitel, which underwrites free distribution of its terminals by substituting them for its printed yellow and white pages. Although Minitel says it will begin charging (about $1.75 per month) for an upgraded generation of terminals now being installed, the advertising on the directory service has proved profitable.

While Minitel is structured like a Bell



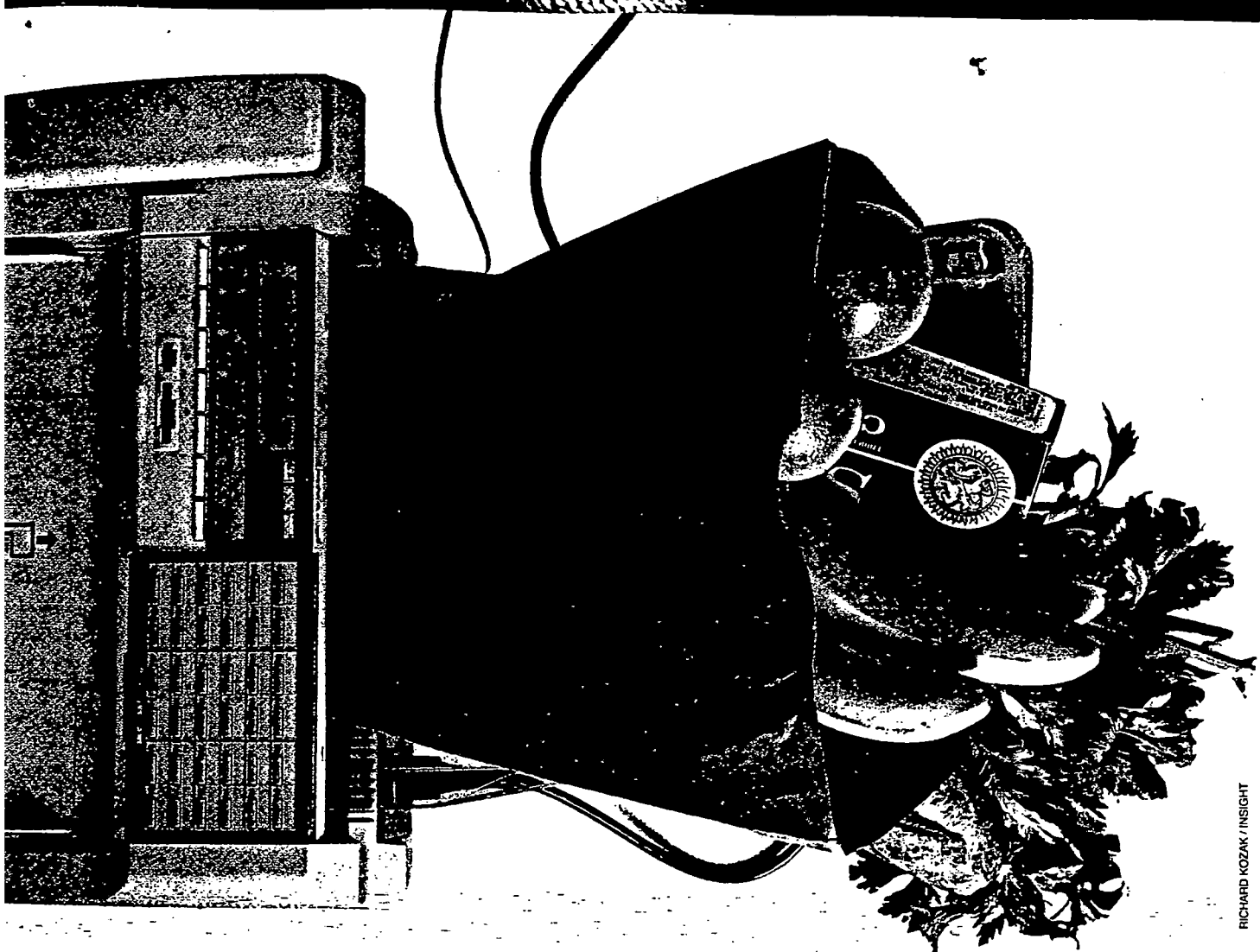
The administrator of the National Telecommunications and Information Administration, **Janice Obuchowsky**, serves as assistant secretary for communications and information at the Commerce Department. Her administration allocates radio spectrum to the government and manages the Institute for Telecommunications Sciences in Boulder, Colo., and provides grants for the facilities of public television.

Most important, however, she is the president's chief adviser on telecommunications. Young, smart and fast-tracked, the Wellesley College graduate and onetime editor of The Georgetown Law Journal is the stuff Dewar's ads are made of, although she is much too serious for that.

The former executive director for international affairs at the Nynex Corp. is concerned that the United States remain an influential competitor in the global communications market. Although she finds the word competitiveness worn, she preaches its importance. A pragmatist, she told the Telecommunications Industry Association in a speech in November that "economic miracles must not be achieved through market manipulation, whether that manipulation comes in the form of dumping in the U.S. market or creating trade barriers in domestic markets."

A middle-of-the-road Republican, Obuchowsky is still groping for her public sector style. Already she gives signs of being a percentage player, one who fits well in the Bush administration. She is long on the bromides of bureaucracy: "Our educational system has seemingly lost its ability to consistently produce students with a sure grasp of basic knowledge," she said in the same speech — hardly a controversial view. ■

TELIC ALCATEL



RICHARD KOZAK / INSIGHT

company gateway (it provides the mall but does not open competing shops, at least for the most part), it does own its profitable white pages and is part owner in the private company that produces its yellow pages. To that extent, at least, Minitel owns the mall and one or two of the stores.

"This is why these restrictions on the Baby Bells make no sense," says Pearce, now with Bellcore, or Bell Communications Research (AT&T's portion of what had been Bell Laboratories before the breakup). "Those are purely artificial restrictions that don't apply anywhere else in the world. It is ironic that British Telecom can offer information services in the U.S., but Nynex [the New England and New York regional Bell] cannot, and British Telecom can use Nynex's facilities to do it."

A curb on AT&T's entering information services was lifted last August. The company, too, had been restricted by the consent decree, but for only seven years. Early speculation was that AT&T might enter the market by forming partnerships or purchasing an information provider like Dow Jones News Retrieval or Mead Data Central. To date, it has done neither.

"There's no reason to assume that AT&T or the Bell companies will be successful if they enter information services," says Gerald R. Faulhaber, an associate professor of public policy and management at the University of Pennsylvania's Wharton School. "That's not what they do. They would be good at purchasing content, not producing it. They would do well as distributors."

Even so, they are limited on distribution because of the monopoly they have on the local telephone network. In essence, their situation potentially allows them crippling control over the competition. As a matter of practice, for example, the Bell companies automatically keep records of all calls within their network — where they begin and where they end. If, as in an example offered by the newspaper publishers, a competitor offered its own information service through a Bell gateway, the Bell company could potentially determine who is calling the competing service, at what hours and from what parts of the phone company's calling area. The Bells would thus have all the information they need about their competition to begin poaching its customers.

This is, of course, a doomsday scenario that would not likely escape regulators at the FCC, but it is also true that because the Bell companies control the telephone network, they could offer comparable services at comparable times on better terms. Or they could see to it that their calls got priority treatment over their competition through quicker and better connections. Complaints to regulators would not likely yield quick remedies. With a Bell company that has yearly operating revenues of $12.7 billion, as does Nynex, an entrepreneurial start-up firm could easily be outmatched in a long, drawn-out legal battle.

"The Bell companies would have every incentive to disadvantage their competition," says U.S. District Judge Harold H. Greene, who, for the past six years, has administered the consent decree. "Two or three years ago, when the issue of loosening restrictions on information services was first before me, the regional companies said, 'If you will just let us into the transmission of information, we will bring about new markets.' They said they weren't after information services. They told me that they could do everything they wanted if they were simply allowed into the transmission business. So I let them in. Now they say, 'If only we had information services, we could do magnificent things.' "

Greene, 66, says that as long as the issue is in his hands — that means until he seeks senior status (semiretirement for federal judges) four or five years from now or until Congress takes the matter into its own hands — he will not allow the phone companies to originate information. This, he believes, will expedite competition with the monopolistic Bell operating companies.

"It is inappropriate for a federal court judge to be making public policy in this critical area of telecommunications," says Rep. Edward J. Markey.

"The only reason I would change my opinion about lifting the restrictions would be if the Bell companies got enough competition to end their monopoly over the local exchanges," he says. The overwhelming majority of calls, about 80 percent of the 1.7 billion local or long-distance calls made daily in the United States, originate, terminate or both with a Bell company.

It is the consent decree that keeps the competition going, the judge contends. There are, however, indications at the margins of competition that the Bell companies are beginning to feel pressured. Large corporations, for example, are developing their own private networks. Rockwell International, for one, can ring its offices the world over, without the local exchange services of a Bell company.

About 1,400 independent telephone companies have sprung up since 1984. However, most of the business is dominated by a handful of firms, five of which control about 95 percent of the independent network. GTE is the largest, operating 9 percent of the nation's network.

In many cases, the "independents" have proved to be more adventurous innovators than their Bell counterparts. In part, this is because of the restrictions imposed on the Baby Bells. In fact, the Bell system has traditionally been slow on the uptake, reluctant to introduce new services. In the years before the breakup, AT&T was continually issuing warnings that such now-commonplace items as the answering machine would somehow play havoc with the phone network.

To that extent, being the only show in town has often worked to the Bell companies' competitive disadvantage. They have not been forced to keep pace with change. "The mentality of the Bell companies," says Arlen, "is to put the equipment in place and depreciate it. In 1976 I wanted call waiting for my home. They told me that it wouldn't be available in my area until 1988, in 12 years. Sure enough, in 1988, I got the form that told me call waiting was available. That was because in 1963 they put in a switch in my neighborhood that had a 25-year depreciation span."

Even today, the most advanced experiments with the phone system are being spurred by the independents. In Cerritos, Calif., about 10 miles southeast of Los Angeles, GTE is testing two futuristic transmission systems, one of which promises to offer viewers (only five at first) a pay-per-view video jukebox. In theory, the jukebox allows household couch potatoes to call up any film they wish, anytime they want, simply by punching in a code on the remote control.

With the ability to transmit full-motion TV pictures over telephone lines a technological breath away, an advanced switching device recently announced by GTE promises to allow video stores to be networked together. That means the stores could transmit their films over the phone lines so that any number of couch potatoes might call up any film they wished, even if 10 or more decided to watch "Back to the Future" at the same moment.

David Markey, a top lobbyist for BellSouth, the regional company that set up the nation's first Bell gateway in 1988, in Atlanta, says competition from the independent companies is brisk. "In New York," he says, "if an independent company got the right 100 buildings wired together, they'd have one helluva business."

The point is that it is not necessary to wire an entire nation together to take a sizable financial bite out of the market. "The independent companies don't have to subsidize their costs to local customers as we do," says Markey. The Bell companies are bound to assure universal service, while independent boutique operations may custom-tailor products strictly for the lucrative high-end business market.

"The major benefits from the new technologies aren't directed at the home market," notes Robert W. Crandall of the Brookings Institution. "They're aimed at businesses. In the U.S. today, nearly two-thirds of all telecommunications is business oriented."

For the residential consumer, competition has produced lower prices for long-distance calls, down nearly 40 percent since the consent decree. But by way of innovations, apart from audio and videotex gateways, the phone companies have offered little, just the proverbial bells and whistles, costing on average $2.20 for each clang or tweet. Some of the latest such offerings: repeat call ($2 a month) automatically redials a busy phone; return call ($4) remembers the last incoming call and

Talking Telecom

Talking telecom is like talking Prussian. It's not really a different language, but you have to be in the caste to know what it means.

Here is a current lexicon of telecom talk:

Busy Hour: Usually comes right before happy hour. Prime time for the phone company. Any 60-minute period during the day when telecommunication volume reaches maximum.

CLASS: Custom Local Area Signaling Service. The switch that allows for call forwarding, caller ID. In this case, something you *can* buy.

ESP: Enhanced Service Provider. A business that sells CLASS.

Group Access Bridge: Allows participants in a conference call to come and go as they please. Or as the boss allows.

POP: Point of Presence. The physical connection at which the local telephone company joins the long-distance carrier.

POTS: Plain Old Telephone Service. Opposite of CLASS.

Roaming Agreement: The terms struck by cellular phone companies among themselves to carry each other's calls.

Twisted Pairs: Not a rock group. Not people to avoid. The oldest and still most common form of telephone wiring.

X.25: CCITT standard governing the interface between data terminals and data circuit termination equipment for terminals operating the packet mode on packet-switched data network. At least that's what "A Quick Guide to the New Telecom Lingo" says. ■



RICHARD KOZAK / INSIGHT

Arlen says the Bell company gateways are not meeting expectations.

redials a missed call; caller ID ($6.50) shows the phone number of the caller.

Chesapeake & Potomac Telephone Co. in Washington, a Bell Atlantic company, offers all three for $11.18 a month, or $134.16 a year. Nine other services, such as speed calling, call forwarding and call block, are also available. Phone companies believe that if subscribers unflinchingly pay $24 to $40 a month for cable TV plus premium channels, then telephone users might be fair game for the extra charges of their enhanced services.

How much more it will cost for features like video wallpaper is anybody's guess. For now, the battle is over who gets the right to offer the service. The big contenders are the Bell companies, the cable television companies, the independents or some upstart entrepreneur.

The first inkling of an answer may come from the District of Columbia Circuit. The court is hearing an appeal on Greene's ruling that the Bell companies should not be allowed into information services. Richard Levine, who helped draft the consent decree and now is associate national director for telecommunications regulatory services at Touche Ross, thinks an answer might come in six to nine months.

A quick ruling hinges on whether the court sees the Bell companies as having the same First Amendment rights to distribute information as newspaper publishers. Says Levine, "There's a 60 percent or better chance that something will come out of the appeal that will increase the Bell companies' ability to provide information services."

The Justice Department, which negotiated the consent decree, is wading into the appeal on the side of the Bell companies. Nancy Garrison, assistant chief of the communications and finance section of the Antitrust Division, worked on the government's case. "The question isn't really whether discrimination is possible," she says. "It is whether the extent of the risk that anticompetitive conduct will actually occur will cause an adverse effect on competition. We assessed that and the various regulatory safeguards, and concluded that while there is possibility for discrimination, it would not impede competition."

No matter what the appellate court decides, pressure on Congress is creating political realignments and the potential for agreement, if not yet legislation.

The Senate Commerce Committee's Cohen sees little hope for a bill in 1990 that will free the Bell companies from the consent decree. "If the Congress thought the court was out of line, you would have seen legislation by now," he says.

More to the point, Cohen cites as missing any sort of ground swell of public opinion that might move Congress to legislate. He quotes former House Speaker Thomas P. O'Neill Jr.: "All politics is local."

"The thing that really matters," Cohen adds, "is whether my bosses' constituents are complaining. You only hear from them on pocketbook issues. That's why there's so much talk now about reregulating cable television. What the public cares about is cost and quality.

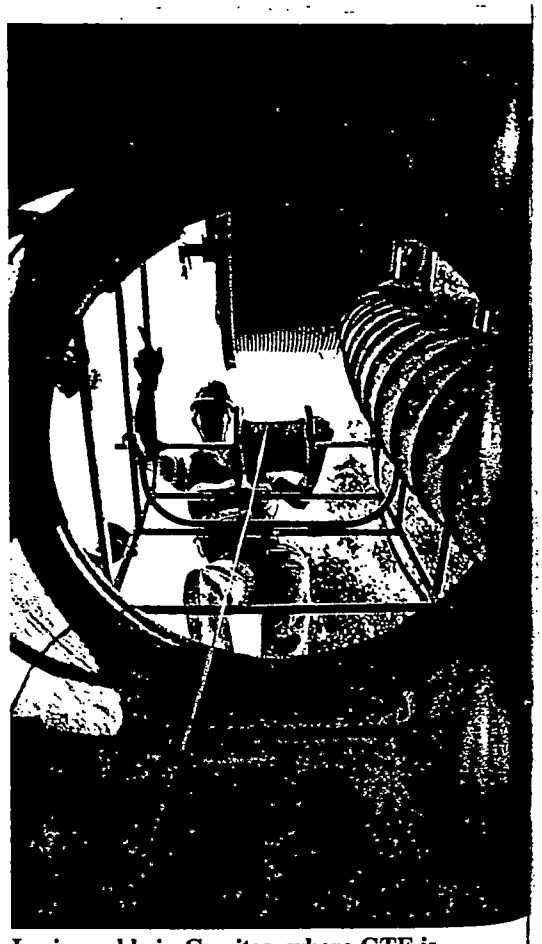
Before Congress recessed in December, Cohen's boss, Sen. Ernest F. Hollings, a South Carolina Democrat, introduced legislation to allow the Bells into manufacturing, citing a need to jump start U.S. competitiveness.

"Politicians are problem solvers," Cohen continues. "They get credit for that. Russell Long said, 'Don't ask me to come in and deal with something speculative, something the public doesn't see as a problem. There's no credit in it, and if I screw up I get the blame.' "

Cohen says the Senate is waiting for the House to take the lead. All eyes are on Markey's subcommittee, which held seven hearings on related matters in 1989. "It is inappropriate," says the congressman, "for a federal court judge to be making public policy in perpetuity in this critical area of telecommunications."

The statement brings Markey in line with his committee chairman, Michigan Democrat John D. Dingell, as well as Texas Democrat Jack Brooks, the new chairman of the Judiciary Committee and its Economic and Commercial Law Subcommittee. Brooks, who is still something of an unknown on the issues, could prove to be a spoiler. He held hearings on the antitrust issue before the subcommittee in August. There, he expressed misgivings about the opening of information services to the Bell companies. Nothing will emerge from the House without Judiciary Committee approval. Brooks was ill for much of the fall and unavailable for comment.

In 1988 the House failed to consider a communications bill, known as Swift-Tauke (for sponsors Thomas J. Tauke, an Iowa Republican, and Al Swift, a Washing-



GTE

Laying cable in Cerritos, where GTE is testing its video jukebox system

ton Democrat), which aimed to free the Bell companies from business restrictions. Swift-Tauke Part 2, the bill's sequel, failed again to attract support in 1989.

Gary Arlen reports that Markey will introduce a bill of his own in early January to allow the Bell companies into information services. "One goal of Markey's bill will be to limit the scope of Judiciary Committee involvement," Arlen wrote in the December Interactivity Report.

"The question that I have made the centerpiece of our discussion this year," says Rep. Markey, "has been which powers, and in what time frame and in what regulatory framework, we could create legislation that would provide the maximum benefit to consumers through the promotion of competition." What he means is open to debate, but aides in Congress say he wants to free the Bell companies while finding a regulatory framework that will also protect competition.

Markey's cake-and-eat-it commitment may be politic, but it is not out of the realm of the possible, particularly because of changes in the FCC. During the Reagan years, Congress criticized the commission for playing fast and loose with deregulation. Two former chairmen, Mark Fowler and Dennis Patrick after him, challenged the Hill on such issues as the fairness doctrine, which was favored by Congress and opposed by the FCC. The commission said it cheated broadcasters of their First Amendment rights. The doctrine required equal time over the airwaves for contrasting political views.

The new commission chairman, Sikes, is better liked on the Hill. "I have had a working relationship with Al Sikes for most of the 1980s," says Markey of the former administrator of the National Telecommunications and Information Administration. "He has a pragmatic approach to telecommunications policy which makes legislation possible."

Sikes, who favors allowing the Bell companies into information services and manufacturing, expresses confidence that regulation can replace the consent decree while still protecting competition. "We have to make certain that information entrepreneurs will be able to take advantage of the public network, because they're the ones who are going to keep the Bell operating companies alert."

Sikes has sharply pointed up the telephone industry's shortcomings. In an October speech to the United States Telephone Association, a powerful lobby supporting the Bell companies, he said, "For an industry with such substantial revenues — and growing profits — the level (and extent) of innovation seems remarkably small."

Narrowing his sights on the Bell companies, he made clear that instead of putting their money into innovation, they were using it to carve up established markets. "Many of the Bell companies in recent years have spent huge sums purchasing cellular mobile telephone properties, amounts that dwarf their expenditures on network innovations and experiments."

Asked if he thought allowing the Baby Bells into information services would change that, he demurs. "I've seen them become more competitive, in part because of domestic competition. I think more competition will force them to be more entrepreneurial."

Missing in action on the issues is the Bush administration. The National Telecommunications and Information Administration, the president's policy adviser, is busy with new studies but still awaiting a signal from the Economic Policy Council on the administration position. "Historically," says Administrator Obuchowsky, "we have been opposed to the restrictions on information services. With the advent of the Bush administration, we decided to step back and take a fresh look at where we're going." She admits that the administration is waiting for others to take the lead. "There is no policy for now," she says. "We're trying to keep our powder dry until the issue resurfaces as a legislative proposal."

She seems to be champing at the bit, however, convinced that competition can be protected through regulation. "The reality," she says, "is that the regulatory process has been revolutionized since divestiture, and there is a smart, seasoned, centrist team at the FCC that can carry out those rules.

"There's also competition," she adds, "and while it's not strong enough to discipline the Bell companies in the marketplace, it's not a bunch of naive babes in the woods, either. Most of them are capable of policing the Baby Bells and reporting a grievance that slips through the regulators' net."

The choice of who gets to sell the consumer video wallpaper hinges on whether allowing the Bell companies entry into information services will stimulate competition or stifle it. There is agreement that the process will be one of inclusion rather than exclusion. But there is no mandate as yet to set opinions herding around one particular point of view, and the challenge of doing so is at least as great as trying to get hippos to perform ballet. "Back to the Future Part II" may have successfully portrayed the telephone of tomorrow, but the next few months will explain how we get there.

— *Jeff Shear*



The Bush administration is waiting for Congress to make the first move on telecommunications policy. In Congress, the Senate is waiting on the House, where the Judiciary Committee is keeping a close eye on the Telecommunications and Finance Subcommittee. There, all eyes are on the subcommittee chairman, **Edward J. Markey**.

He is giving clear signals that he thinks he might be able to find a way to free the Bell companies from restrictions on manufacturing and information services established during the breakup of AT&T. The trade press, perhaps overly optimistic, is expecting a "Free the BOCs" bill for the Bell operating companies from him before January is out.

Questioned directly about such a bill, the Massachusetts Democrat appears to go grabbing for his prepared talking points.

"The question I have," he begins, "is, what should the structure and regulation of the telecommunications industry be in order that there will be long-term benefits to the consumers through the promotion of competition?"

To answer that question, Markey must first produce the legislation necessary to get the matter away from the courts. He has been discussing that for nearly a year. Ultimately he will have to contend with Alfred C. Sikes and the FCC, because it is they who will have to guarantee those "long-term benefits" to consumers.

Markey sees himself helping to shape this large and critical industry. To do so, however, he will have to begin making some difficult decisions. Those will probably have to wait until after the 1990 election. ■

GTE

BATTLING THE TELCOS

In the fiber-optic nightmare of publishers and broadcasters, Americans will soon be getting their news from editors at the phone company.

For most of us, the telephone is simply a device for calling Aunt Sally or driving our new fax machine. But the telephone lines that enter homes in America have far greater potential to serve and entertain us. Already, using existing copper lines, telephones can deliver instant news to video-display screens and provide a broad array of related information services ranging from access to the local library to data bases worldwide. But that's only the beginning.



CHUCK O'REAR/WOODFIN CAMP

In the not-so-distant future, fiber optics will dramatically change the role of the telephone system, enabling it to deliver, among other things, high-definition television signals. Information is a hot commodity. The potential consumers are as numerous as telephone users, and the stakes are in the billions. The fight is on.

How will information be delivered in the future and who will control the means of delivering it? Because the present telephone network has the potential to be the chief information carrier, access to the single wire attached to the telephone is the prize. The blistering fight for

RAY DRIVER

BY JEROME AUMENTE

control pits the newspaper publishing, broadcasting and cable television industries against the seven Regional Bell Operating Companies (known as RBOCs or telcos), which control 80 percent of all local phone service in the United States.

What the seven telcos want is nothing less than permission to produce and sell news and information in voice, video and text formats over their own lines—not just carry other people's messages. U.S. District Court Judge Harold Greene, who has presided over the break-up of AT&T for a decade, had barred the RBOCs from getting into the information business in 1987. His rationale: As proprietors of a single-line, they would have an unfair monopoly on the opportunity to sell other services.

With a $21 million war chest to help get their message across to Congress and the public, the RBOCs have mounted a vigorous legislative campaign in Congress and in the courts to eliminate those restrictions. On April 3 a three-judge panel at the U.S. Court of Appeals in Washington handed the RBOCs a crucial victory, overturning a key portion of Greene's '87 ruling. The court sent the case back to Greene, directing him to use different criteria in determining whether to lift the restrictions on information services.

The issue, say the RBOCs, is free speech. The problem, say the broadcasters and publishers, is control of information. But nobody is denying that the communications landscape will change dramatically if the phone companies can bring television and radio programs, text information, online services, and voice services, including audiotex and voice mail, to individual consumers. If the telcos were also the owners and producers of that information, the change would have an even greater impact—possibly changing the nature of the information received. And *that* the broadcasters and publishers find unacceptable.

"I think it's silly," says Nancy Woodhull, president of Gannett News Service. "The credibility of the information is extremely important. Some people who invent this technology think that anybody can run around being a journalist. But it's a profession, and either they are going to have to get into the journalism business and hire journalists or they are going to have to work with the people who are journalists already.

"The public is very smart. They don't want someone whom AT&T hired writing about Bush's speech last night. They want a journalist who knows how to ask the questions that need to be asked. Can AT&T really get into the journalism business? It is not their area of expertise. It is just like me wanting to go around and run a phone company."

Vowing a fight all the way to the U.S. Supreme Court, BellSouth Vice President John R. Gunter says, "We are not a news-gathering agency and don't intend to become one." But the company would like the opportunity to provide such things as traffic reports to cellular car phones or wire service news summaries, he says. "We don't want to be the only information provider. In fact, we don't even want to provide the majority of it. We just want to be one among many."

Gunter says arguments that the Bell companies will stifle diversity is a "hollow" one and that news media opponents are motivated more by business concerns. As to fears that they control the single wire into the home that someday might carry the bulk of video, voice and text services, Gunter says existing legislative and regulatory safeguards will prevent monopoly abuses.

And, he adds wryly, nowhere in the Constitution is there a clause saying, "You have the right to free speech unless you are a telephone company."

The issue, say the Regional Bell Operating Companies, is free speech. The problem, say the broadcasters and publishers, is control of information.



Fiber Optics Are Coming

One thing is certain: The inevitable replacement of copper telephone wires by fiber optics—the communications equivalent of replacing a small stream with Niagara Falls. Quantity is the obvious advantage of fiber optics over the copper wires used for POTS (Plain Old Telephone Service). Instead of one wire, laser impulses are transmitted through—potentially—thousands of thin glass strands, each a channel for voice, data, text and video services.

How the contest between the telcos and the traditional information industries is resolved could very well determine how quickly the United States will move toward creation of a nationwide fiber-optic network to replace the copper wires.

"Fiber is going to come," says John D. Abel, executive vice president of operations at the National Association of Broadcasters (NAB). "There are a lot of reasons why it should come, and it's NAB's view that it is good for America. It is a very powerful thing to have such unlimited broad-band capability. It is like building the new interstate transportation system for America—only this

is a communication system."

With five billion phones worldwide, he says, the day will come when a user can dial up "every product of human endeavor, all books that have ever been produced, all journal articles and magazines, all newspapers, all television programs, all movies, photographs of famous art works—anything that you can put in a digital storage device. We can give you a menu at home that you can access that includes all television stations, all radio stations."

Making that happen will require construction of a local fiber network with an optical switch to let electrical and optical signals interact, as well as sufficient storage capacity to handle content. Most experts predict the hurdles can be overcome.

Monster Monopolies?

Abel insists the Bells must keep out of the information-ownership business "to prevent a monster being created like the cable industry, which has ownership of the distribution facilities and ownership of the content for multichannel capability."

With a virtual monopoly in most areas, cables have enormous powers—including the ability to determine what signals are carried and what signals are not carried. Disputes such as these can make for strange bedfellows. Broadcasters, who resent the advantages of the cable industry, want to see it re-regulated—made to carry its broadcasting signals and ordered to pay for over-air broadcast programs it now provides to its subscribers. To that end, they have been discussing with the phone industry what role a fiber network would offer as an alternative to cable. These discussions give NAB an interesting bargaining chip and a pressure point in the cable controversy.

Still, the NAB adamantly objects to any content origination by the Bell companies, and any joint ventures or ownership of information originators. NAB also vehemently opposes moves by the telcos to purchase cable interests anywhere, calling them backdoor attempts to get into the information business.

The NAB's Abel reflects concerns, shared by publishers and cablecasters, that the telcos would engage in predatory pricing. NAB fears the telcos would use telephone revenues to subsidize new information services and displace traditional media operations. At present, revenues from basic service are strictly limited to providing that service and are not allowed to be used to seed other money-making ventures.

W. Terry Maguire, senior vice president of the American Newspaper Publishers Association (ANPA), helped guide the tactical moves in the long fight with the telephone industry. He says ANPA steadfastly opposes the RBOCs getting into the information business in their own service areas: "It is fairly simple—the fact that there is only one telephone line in town. There are no other alternatives, including cable, capable of doing what a telephone can do to move information. It is the only medium in town, and our concern is that if the phone company owns or controls some information, it is going to have the incentive to favor the information in which it has an ownership interest to the detriment of information where it does not have control or financial interest."

In The Courts

Last summer Judge Greene allowed a seven-year ban to elapse on AT&T's ability to enter into electronic publishing. His reasoning: There was sufficient competition in the long-distance area—a move ANPA supported. Now, with the Appeals Court ruling, Greene has to reconsider letting the Bell companies get into the information business.

He has already allowed the RBOCs to initiate videotex and gateways (information-service clearinghouse lines) to be used by other information providers to do billing, handle voice mail, message storage and forwarding. But all are "content-neutral"—the telcos cannot change or enhance the information.

Newspapers feel the RBOCs should be kept out of the field of information ownership. They see their position vis-a-vis the RBOCs as somewhat unique. Certainly entry of the Bell companies into the information field would represent competition that would likely erode newspaper readership and advertising revenue. But the ANPA's Maguire also feels newspapers have a special function—that of unifying readers in an information market already fragmented by special interests. He sees the newspaper as an anchor—with the phone being able to deliver complementary services.

Newspapers already use phone lines for certain distributive services—audiotex, videotex and fax—to provide on-demand news and information, promote full reports in the next day's paper



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ANPA's Telecommunications Department reports that more than 20 newspapers run interactive audiotex, mostly ad-supported, with readers using touch-tone phones for news and information. Some papers have pay-per-call ventures to access classified ads. Newspapers are on every RBOC gateway, and at least five papers now use fax delivery of news and information—called faxpapers.

The publishers do not oppose the RBOCs going into information services outside their service areas, where they would not have a monopoly advantage or access to crucial marketing data on phone use.

Several congressional committees are considering legislation that would let the RBOCs into the electronic information business. Bell companies do provide gateway lines, but the key is open access.

David E. Easterly, president of Cox Newspapers, told the House Subcommittee on Telecommunications and Finance that Bell companies publishing on their own lines could hurt competitors by "being slow in handling service problems; drag their feet in sharing market data, and in subtle ways, deploy their own advanced technology to favor their own services." He said that happened in Atlanta and West Palm Beach where a Cox newspaper could not get a special-access number to start a voice mailbox service—only to find BellSouth later starting its own.

Newspapers take the electronic publishing revenue potential seriously. Easterly testified the field has an annual growth rate of 17.9 percent and employs 1.2 million people in the information-services industry. He counted 1.6 million videotex service customers and an expected 45 percent growth rate. Electronic database services generated $6.2 billion in 1988, had 1.5 million customers and forecast a $15 billion annual business by 1992.

Although electronic information services are flourishing, *Newsday* Publisher Robert M. Johnson testified before Congress that the Bell operating companies own the lines and run them. "They have a bottleneck monopoly," he said, "and now they want to get into the publishing business on their own. The RBOCs already control the medium, and now they want to control the message. That is not a level playing field. It is not even just a home-field advantage. It is like asking their competitors to play ball in a swamp."

Johnson further claimed that many of the RBOCs "have resisted fully developing the gateways in the hopes of dismantling Judge Greene's restriction on them and entering the information market with an inherent advantage."

BellSouth's Gunter says the individual RBOCs differ as to how much they want to get into information content, but BellSouth has a keen interest in it. It wants to protect its lucrative directory business, and as it moves toward electronic delivery, offer audiotex supplements—not only locate the lumber yard, for example, but provide that day's plywood prices—all with a single phone call. Someday, he predicts, there will be video supplements to the voice and paper products.

Just as video-cassette recorder sales took off when movie rentals generated buyer interest, the videotex field needs to be jump-started, Gunter says. He believes electronic yellow pages could be the "anchor tenant in the electronic mall" to attract a mass of average householders to dial-up computer-based services. He points to the thriving government-supported videotex system in France, which has 11,500 information providers and nearly a million users. The French have found the electronic phone directory, which garners 20 percent of all inquiries, the largest single draw.

There are already nearly 5 million miles of fiber in long-distance and switching-station connectors in the United States, and Gunter says a local phone-fiber network is inevitable. Predictions vary as to when the cross-over point will occur when fiber becomes more economical to install than copper wire. Some forecast it as early as 1992-1995; conservative estimates put it 10 years away.

Newspapers take the electronic publishing revenue potential seriously. . . The field has an annual growth rate of 17.9 percent and employs 1.2 million people.



Cable Company Fears

The National Cable Television Association (NCTA), facing major competition from a phone-fiber network, says RBOCs are trying to slip into the television business because they need the revenues it would generate to justify a fiber network. NCTA claims the conversion would cost anywhere from $450 billion to $900 billion.

Gunter says the fiber network estimates are "wild numbers" incorrectly projected by extrapolating prototype lab costs. He says normal replacement of copper-wire systems and installation in new construction of homes and offices by BellSouth will cover a significant part of its fiber installation.

Paul Rogoski, public relations director for the United States Telephone Association (USTA), the trade association for most of the nation's local carriers, says a local fiber network will cost about $220 billion and notes the phone companies spend $21 billion a year now to upgrade lines so that the cost would be covered over a 10-year period.

But arguments over installation costs mask the real concerns of the cable companies. John Wolfe, spokesman for NCTA, says the cable companies have faced decades of "anticompetitive conduct" from the telcos, who unsuccessfully fought to keep cable off telephone poles. "Since divestiture, our concern is with the incredible monopoly and power granted to the local exchange carriers," he says. "The phone companies talk about a one-wire world where there is one wire, their wire, going into every home and they also control the content going over that wire—and in terms of the diversity-of-voices argument, that is deadly.

USTA's Rogoski counters that it is in the telco's interest to encourage maximum use to generate revenues—not stifle it. He said the competing industries, consumer groups, the FCC and state regulatory agencies will provide adequate oversight to prevent abuses.

Meanwhile, the NCTA's Wolfe says the cable industry is active in Congress "trying to blow away the smokescreen the phone companies have laid out. [The telcos] are trying to create the impression that unless they are able to get into TV content, they can't possibly bring America the promise of fiber."

Wolfe says that if the telcos "are successful in wiring the entire country for fiber, you wouldn't need broadcast television anymore." When pressed, he also concedes the same would apply to cable television. There is no doubt that fiber-delivered television would have a profound impact on viewers. NAB's Abel says the end of the over-air broadcasting would be bad for America because it would end free television access. He notes that even today, with 58 percent of the households subscribing to cable, 62 percent of all TV sets are not actually hooked into cable, which means only 38 percent get a wired signal. Wire delivery might have similar limitations.

If fiber does come, Abel says broadcasters could use its higher band capacity for high-definition television, while still offering conventional TV for over-air signals. Fiber could also help ease interconnection service problems for television networks that feed local affiliates. He says it is silly to send a signal 22,300 miles into space and bounce it back when it is only going 35 land miles. "Fiber can do it more effectively. It is not affected by weather. It has great security and high quality. Fiber is definitely a superior medium, and switched broadband facilities are the ultimate in what can be done on a terrestrial basis," he says.

In the meantime, small, local phone companies, not affected by the ban on content control which limits the larger RBOCs, are experimenting with full fiber-to-the-home services. And Bellcore, the research arm of the Bell companies, is testing fiber in 12 cities to deliver television signals from the networks to local television affiliates.

Everyone is waiting to see what AT&T will do with its newfound freedom to get into the electronic information business. But like a giant ocean-liner, it takes time to shift direction. AT&T is fibered, but it must wait for the local carriers—the bottlenecks—to fiber up and open the full range of delivery possibilities.

While AT&T says officially it has nothing to report, insiders say the corporation is talking with Nintendo. The video-game powerhouse may be the opening wedge into a general home-consumer market for electronic services. Sources at Bell Laboratories say they are conducting various electronic publishing experiments, including one with the Japanese.

In reality, AT&T was so focused on reorganization after divestiture that some say it actually used the ban against getting into information services as a breather until it got its new house in order. After a shaky start with computers, it has hit its mark in networking services. Now its various business and consumer entities are looking at a range of enhanced information services to sell via phone links.

What should not be forgotten is that in the early 1980s AT&T participated in a variety of joint ventures with newspapers and broadcasters who were trying videotex experiments. Its Venture One activities with CBS and IBM actually formed the prototype for Prodigy, a growing national videotex service. Owned by IBM and Sears, Prodigy grew out of Venture One research.

Now AT&T has the green light from the courts and Judge Greene to harvest its own electronic publishing crops. With the recent reversal of Greene's ruling, broadcasters and publishers worry that the telcos may not be far behind. •

Professor Jerome Aumente is director of the Journalism Resources Institute at Rutgers University in New Jersey.

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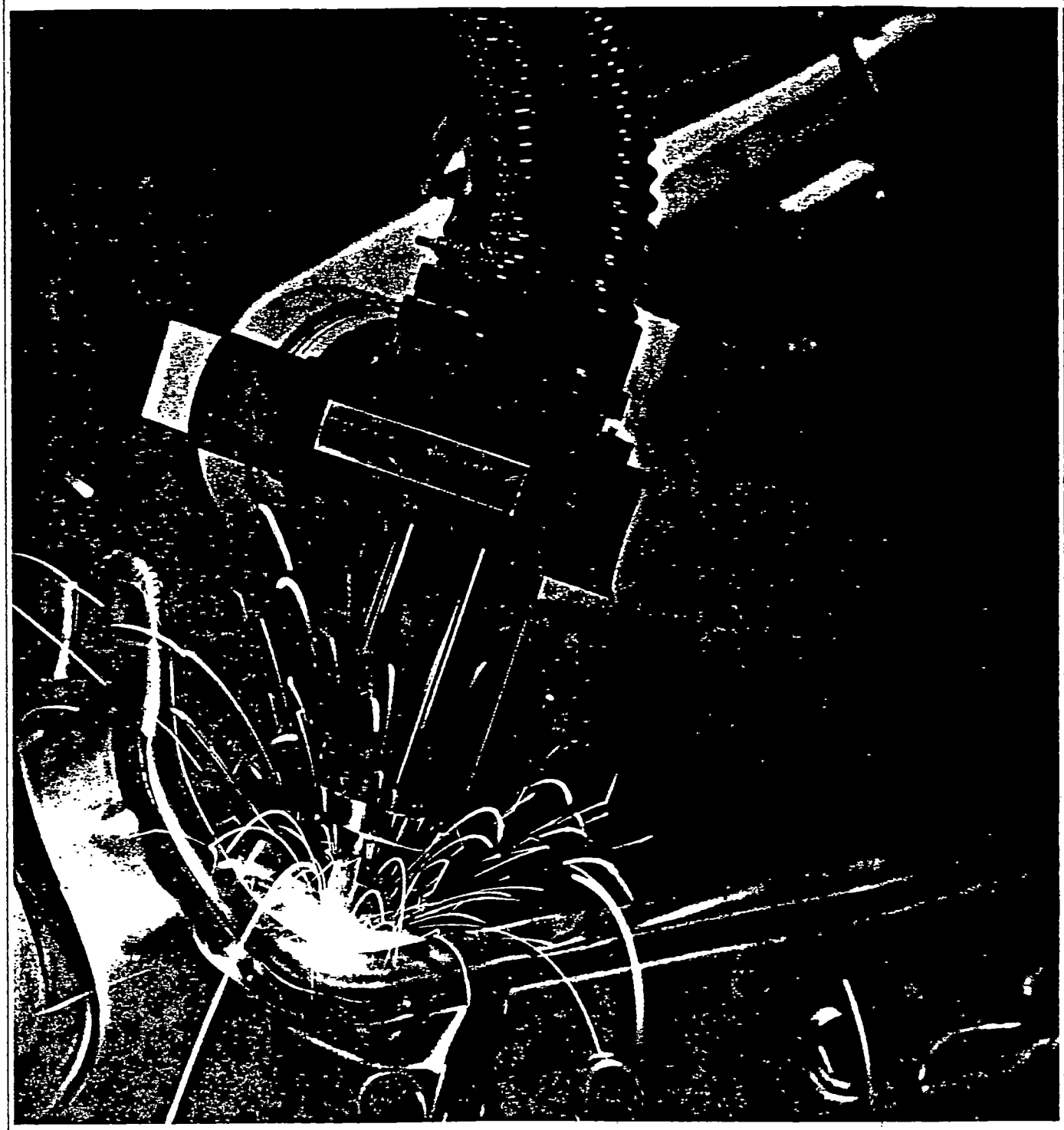
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Factory of the future



A survey

The Economist

FACTORY OF THE FUTURE



The challenge

The factory is being reinvented from scratch. Traditional production lines are being ripped apart to make room for flexible "make-anything" machinery. Nicholas Valéry comments on the coming battle for competitiveness between manufacturers East and West

Imagine, if you will, an engineer sitting at computer terminal punching in data for the design of a new product and sketching freely with a lightpen on the screen before him. Happy with the design, he presses a button and the details are passed electronically to another computer running software that checks to see whether the design's stresses and strains are within prescribed limits. The information then zips along to a third computer which generates instructions that command the tools in the workshop to machine, assemble and store the engineer's product ready for distribution—all done automatically, without hassle, delay or hefty manhandling, and all before the morning's coffee break. One more satisfied customer.

Welcome to the "factory of the future". For the first time in three-quarters of a century, the factory is being reinvented from scratch. Long, narrow production lines with men crawling all over them—a feature of manufacturing everywhere since the early days of the carmaking dynasties—are being ripped apart and replaced with clusters of all-purpose machines huddled in cells run by computers and served by nimble-fingered robots. The whole shape of the industrial landscape is changing in the process.

The name of the game in manufacturing has become, not simply quality or low cost, but "flexibility"—the quest to give the customer his or her own personalised design, but with the cheapness and availability of mass-produced items. Savile Row at High Street prices. In short, nothing less than a whole new style of manufacturing is in the process of being defined. As firms seek to add extra value by customising their products, while managing somehow still to make them at affordable prices, the concept of "economy of scale" is being transformed into an idea best expressed as "economy of variety".

The chart on the next page shows where this technological push is leading—into a magic kingdom where elements of the mass-production of Henry Ford and the craftsmanship of Peter Fabergé co-exist. More than anything attempted so far, more than any amount of retooling, more than all the brave efforts to solve manufacturing problems by hurling raw technology at them—this finally is what the ephemeral factory of the future is really all about.

High-tech manufacturing is America's answer to all the onslaughts on its markets made this past decade by aggressive competitors from East Asia. Midwife at the birth of this brand new form of automation has been the Pentagon, concerned that yet more of its contractors might be bruised by near-bankruptcy as Lockheed and Chrysler were, and that tanks tomorrow may have to be bought from Toyota instead.

The catch-all title for the set of technologies involved is CIM (computer-integrated manufacturing). Popularisers portray CIM as a plant that pools all its data—whether from manufacturing, marketing, planning, personnel and finance departments—so that the factory's machine tools may be reprogrammed instantly, and as often as necessary, in order to make whatever customers demand or the business forecasts

suggest. Want a new left-handed double-threaded widget in pink plastic? Whiz-bang, you've got one. This is how the factory of the future is supposed to function.

Actually, a few heroic attempts come pretty close. All told, there are now 30 or so factories working in the United States that exploit CIM extensively; many of them (like LTV's Vought plant that produces the B-1B bomber) are veiled heavily in secrecy. In Europe, perhaps half that number are in operation. And in Japan, almost none.

None? Few Japanese manufacturers have as yet anything like enough software savvy to crunch the numbers for a CIM plant. And that may be a blessing in disguise. For, as many an American firm has found, the factory of the future can be as disaster-prone as anything conjured up by Charlie Chaplin or Fritz Lang. Even so, CIM has become a kind of holy grail. With all the trappings of an industrial crusade, CIM (or something much like it) is the big stick America is going to be wielding in the coming battle for global competitiveness.

At stake, says the Department of Commerce in Washington, is nothing less than the future of the country's manufacturing base, worth $300 billion a year and employing 20m Americans. Determined not to be left too far behind are the Europeans, with 27m people employed in a manufacturing sector that contributes $240 billion to the Community's economy. And then there are the Japanese, possessors of the most productive manufacturing industry of all, where 15m workers generate $350 billion a year. With a wholly different perspective on manufacturing, the Japanese have their own ideas about how to build a factory of the future. Who, then, is the most likely to survive in these difficult, promising, challenging, modern times?

When markets go into overdrive

Product cycles are shortening dramatically. Car models, once in production for 12 years or more, are now being replaced every six years. Electronic gadgets no longer remain in production for three years, but three months. Factories are having to become more responsive, more flexible and capable of making anything

The personal tape-players made for last winter's market were bright pastel shades—easier to spot when dropped on the snowy slopes. This spring, customers want them waterproofed as well—for use by the pool or on the beach when the warm weather comes. Back then to the drawing-board so that yet another new design can be on the shelves in three months' time.

In the early 1980s, the product life of most manufactured goods was still averaging around six years. Big-ticket items like cars stayed in production (with minor face lifts) far longer—even a dozen years or more. Domestic appliances such as refrigerators and washing machines lasted typically for five years. Four years separated successive generations of microchips. Even in consumer electronics, product life-cycles rarely dipped below three years.

That has all changed—for which blame consumers as well as manufacturers. Since the last recession, many of the young with jobs now have better-paying jobs; and the wealth has spread to new markets—in East Asia particularly. With it has gone the voracious consumption habits of young westerners. Rich, cocky and acquisitive, teenagers in Tokyo are demanding instant gratification, too. The "me now" generation has arrived with a vengeance in Japan.

But it is not all demand pull. Many manufacturers searching for a way out of the recession marched their troops blindly into the same market niches. Big Japanese manufacturers have been arguably among the blindest—and certainly the quickest to cannabalise their own businesses.

So much so that in Japan's leading manufacturing industries (semiconductors, home electronics, appliances, clothing, and so on) there are nowadays at least half a dozen leading brand names, each with a big investment in shiny new production equipment that requires a market share of anything from 25% to 40% to get its money back. With that kind of overcapacity, the manufacturers need markets twice as large as they have just to break even. Such a level of demand is not around—neither at home nor in the now soft-currency markets abroad. So ritual *seppuku* in boardrooms across Japan as famous firms go bust or withdraw from the business?

Don't you believe it. In image-conscious Japan, to admit defeat would mean unspeakable loss of corporate face. Besides, many of Japan's leading manufacturers belong to big diversified groups, so most can (just about) afford to stay in the game for the time being and meanwhile raise the stakes. This means launching the next generation of products long before the factories for making the present ones have moved out of the red. At the same time, each competitor is being forced to put up even more money for the next cycle of investment, in an urgent attempt to capture the market share needed the next time round.

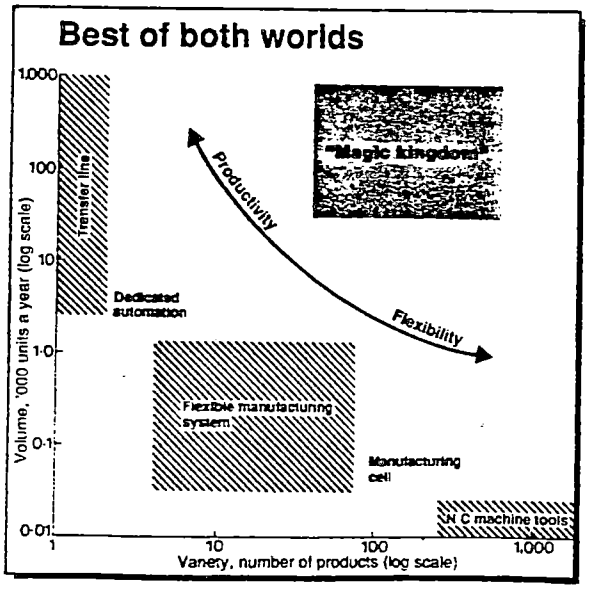
Product-life cycles are therefore being shortened, in some cases to months instead of years. Retailers reckon that the average life of an electronic gizmo on the streets of Tokyo today is indeed no more than three months.

What would Henry think?

The need for greater responsiveness to consumer tastes means becoming more flexible in terms of what you can make and how. That, in turn, means achieving a better balance between the cost of building new plants on the one hand and the unit cost of the goods produced by them on the other.

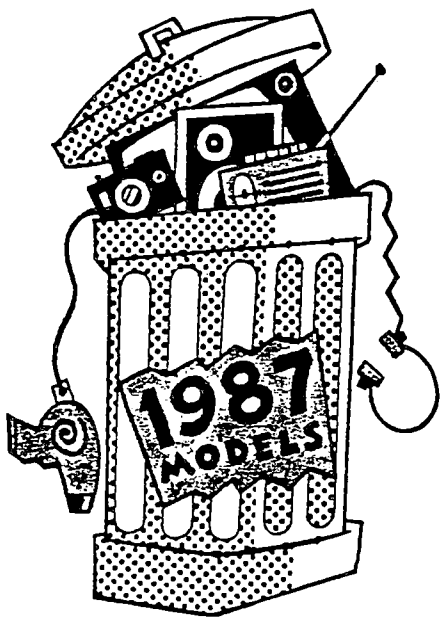
This is age-old dilemma. It has bothered every factory planner since Adam Smith. A pragmatist ever, Henry Ford deemed flexibility impossible (correct at the time) and plumped instead for the most inflexible manufacturing process ever devised—which came to be known as the transfer line. The production notions forged in Detroit over the past three-quarters of a century have been adopted around the world, and not just in motor manufacturing. Today, the sound is the same everywhere as production lines rumble along to the clank and roar of dedicated tools cranking out a single model in vast numbers.

Manufacturers nowadays refer to this as "hard automation", meaning



it cannot be reprogrammed but must be ripped out and scrapped whenever a new model is to be made. The motor industry is still the biggest fritterer on such dedicated automation. Carmakers get little change out of $300m when rejigging a plant to produce a new model. Whatever they may say, they are still hostage to the twin tyrannies of conventional manufacturing: economies of scale and standardised products.

Not so firms nearer the other end of the manufacturing spectrum—in the batch-production business. Every week, a company making, say, roller bearings may need to produce hundreds turned to half a dozen



different diameters, thousands of a more popular size, and just a handful of special ones for particular customers. Here the use of a flexible machining centre (FMC) or tools with computerised numerical control (CNC) are a far better choice than any dedicated transfer line (TL).

There is a snag, of course. The unit costs of parts produced in a flexible plant are substantially higher than those of a production line running flat out. Against that, the investment is far less. More to the point, flexible tooling allows additional models to be added to the company's product range at only marginal cost.

Flexibility also confers a curious bonus—one which, if ever exploited to the full, could have a remarkable impact on manufacturing economics. This concerns the way a flexible factory's output can be more easily tuned to meet demand on a daily, weekly or seasonal basis. The implication is that a highly flexible plant, operated in a CIM-like manner, would be able to take customers' orders direct from a showroom's terminals and use them to drive the machine tools—the customer, so to speak, as manufacturer.

That day is still a long way off. Outside a few craft industries, no one (not even Toyota) has yet managed to "build to order"; everyone else "builds for stock". A few charmed suppliers (mainly in the food business) manufacture for the next day or two's demand. Though their orders may be firm, they are nevertheless forecasts based on statistical guesswork. The impact of "build to order" on carmakers—let alone on firms producing more personalised items like clothing, consumer gadgets or even publications—would shake up such businesses dramatically.

That, however, would be nothing compared with the impact of an innovation that leading machine tool makers are trying to accomplish. They are looking for way of pushing flexible machining systems (FMS) more into the domain of the simple but even more adaptable CNC tools at the low-volume/high-variety end of the manufacturing spectrum. At the same time, they are trying to turn FMS into a competitor to the transfer line used in high-volume/low-variety factories around the world.

Their ultimate ambition, of course, is to develop flexible manufacturing processes that offer the best of both worlds—the customisation possible with CNC machines, but with the unit costs that today can be achieved only on dedicated transfer lines. The first major experiment, costing an estimated $130m over the next five years, has been started on ways of manufacturing in this magic kingdom. Predictably it is being carried out by MITI, the industry-sponsoring ministry in Japan. It is the ultimate expression of a concept of factory automation that began with the first crude attempt 25 years ago to get a machine to do a job the way a man does.

March of the iron men

The new tools moving on to the factory floor are nimbler, more dextrous, even talkative—and a good deal cleverer all round

Iron men have been on the march for more than a quarter of a century now. Since the first industrial robot joined the production line at General Motors in 1961, American manufacturers have recruited 20,000 steel-collar workers, replacing many times that number of blue-collar equivalents. In Western Europe, the robot population has propagated even more—to an estimated 28,000 units today. But where western manufacturers seem to prefer their robots sprinkled lightly through their workforces (around six per 10,000 industrial workers), Japanese firms have embraced them (36 robots per 10,000 industrial workers). In modern Japan, more than 80,000 industrial robots are flexing their muscles around the clock.

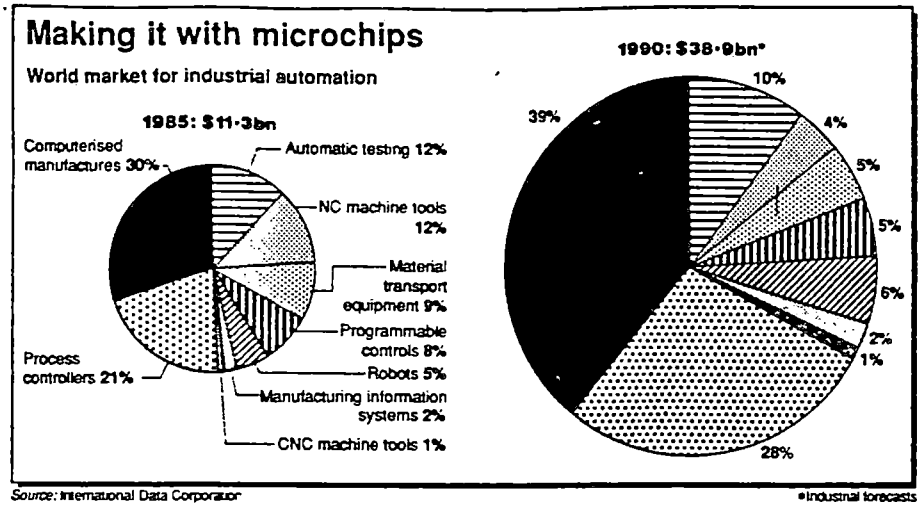
Building robots has become a $1 billion business. Until recently, the biggest customers for them were the motor manufacturers, who have used robots mainly for spot-welding and spraying paint. Now the electrical and electronics industries, especially in Japan, are the biggest buyers. In the process, the way robots are being used is becoming more complex. Carmakers were happy to have them wielding tools (such as spray guns) and working on parts clamped to an assembly line; electronics firms want robots to be able to pick up fiddly bits (like microchips and circuit boards) and join them together. Robots are therefore graduating to the far trickier tasks involved in light assembly.

To do so, they need to be a good deal smarter than their "senseless" predecessors. The second-generation robots now joining production lines are being equipped with such senses as touch and sight. They cannot, of course, see or feel with anything like the subtlety of a human. But their sensors at least let them pick up misplaced parts or make adjustments for inaccuracies in the objects they handle. For the first time, they can start doing rudimentary inspection jobs.

Another first for the new breed of clever robots is an ability to tackle manipulative tasks that are not supposed to arise on carefully laid-out production lines, but do so in the messy human world where components come higgledy-piggledy together before being assembled. Such jobs include peering into, say, a bin of assorted electronic bits and picking out the correct resistor or diode from the jumbled pile, then inserting its leads into tiny holes in a printed-circuit board.

All this technological wizardry has really been conjured up in order to endow robots with the priceless, most human-like capacity of all: the ability to communicate with other members of their tribe. Chattering among themselves, the robots and machinery used in a flexible factory can now report the minutest of details about things like deterioration of their cutting edges or backlash building up in their bearings. That allows the computerised supervisors to make automatic compensations for such errors, thereby keeping the products being manufactured within even tighter tolerances.

As well as arms and fingers, eyes and ears, a tongue to talk with and a rudimentary brain, it would be handy if some members of the robot brigade were also endowed with feet—better still, a set of wheels. This is what the mobile cousin of the smart robot has been given. The AGV



(automated guided vehicle) is a little unmanned truck that follows a cable buried beneath the gangway to ferry components throughout a plant. The significant point is that, without AGVs trundling around the factory floor, the whole concept of "just-in-time" delivery would never have got out of the storeroom door.

Islands of automation

Using fleets of little robot trucks to fetch and carry parts from the warehouse in small batches, even in single units at a time, puts an end to the pallets and binloads of half-finished widgets littering the factory floor. Thus, with machine tools fed just-in-time, components are not allowed to stack up anywhere around the plant, wasting time and clocking up interest charges while nothing is happening to them. With just-in-time delivery inside the plant itself (traditionally it has been used to schedule deliveries from outside suppliers), big savings can then be made to what manufacturers call work-in-progress—half-finished components winding their way through the various manufacturing stages. For the company, economies here have a direct effect on the bottom line; for customers, they mean much faster deliveries.

Nor is this all. Just-in-time allows engineers to start clustering their flexible machine tools into compact "cells" where all the tools needed to make a particular product lie within easy reach. Once a component arrives at a manufacturing cell, all the machining operations happen to it on the spot—so no time is wasted moving it to the next machine tool, adding to its work-in-progress bill.

At its simplest, a cell may contain just a single CNC (computerised numerical control) machine tool. This offers the greatest flexibility of all, allowing a manufacturer to make as many different types of components as he has programs for driving his CNC machine. Inevitably, though, there is a catch: CNC machines are not the cheapest way of making things; and the more of any one product which is turned out in this way, the higher the overall cost.

In more sophisticated cells, the metal-cutting is done on a machining centre—a kind of universal CNC machine capable of carrying out most workshop tasks (including drilling, milling, boring, tapping and threading) without having to change its grip on the workpiece. The trade-off with such a flexible machining cell is the loss of a little of CNC's instant adaptability in return for a bit more efficiency in manufacturing. The full power of this approach comes, however, only when AGVs and smart robots are allowed to join in—linking cells organically into a collection of machine tools under the supervision of a computer.

This is big boys' stuff: it is what production engineers mean when they refer to FMS (flexible manufacturing systems). As FMS equipment clusters into cells around the factory, "islands of automation" arise like volcanic eruptions from the shopfloor. This is still a far cry from full-blooded CIM; before it can qualify as such, the "islands" have to be linked together into a computerised archipelago of machining centres, all communicating with one another and with computers in other departments of the firm.

Even so, FMS units—costing anything from $5m to $20m to install—are the building blocks out of which the factories of the future are constructed. And the number of them being installed around the world is doubling every two years.

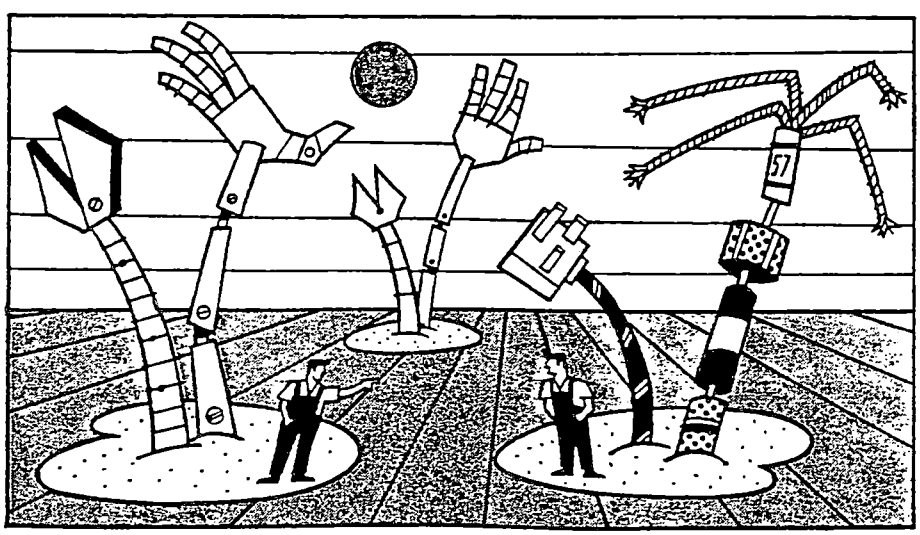
Designer tools

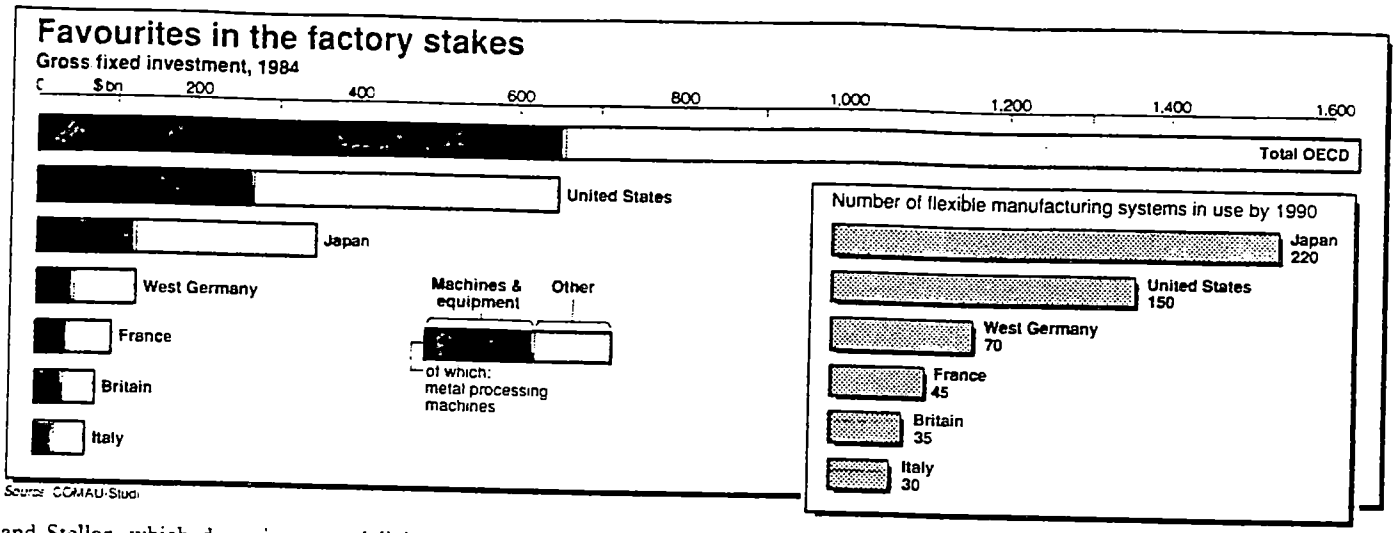
Having intelligent machines capable of making anything is one thing. Getting a picture into their mind's eye of what to make—and a recipe for how to produce it—is quite another. To accomplish this, improvements have to be made in the process by which components are designed. So start first in the drawing office.

Walk into any design shop and if you see dozens of draftsmen at drawing-boards, the company has yet to join the CAD/CAM generation. Computer-aided design/computer-aided manufacturing started life more than a decade ago, mainly as an ambitious first attempt to provide some of the benefits of CIM. At the heart of a CAD/CAM work-station is a powerful desktop computer that can manipulate complex geometrical shapes rather than the simple numbers and words handled by the more common personal computers seen around offices today. The designer makes sketches either on the terminal's screen with a "lightpen" or traces out shapes by steering a marker around the screen using a tiny "mouse". The wiggly lines produced manually are straightened automatically by the computer.

Inside the work-station's memory are details of dozens of standard shapes waiting to be whistled up at the press of a button. Rectangles are drawn simply by specifying three corners, circles by their centres and radii; the computer fills in the rest. And laborious chores like altering sizes, perspectives or cross-sectional views are all done in a trice by the software.

Graphics equipment like this is not cheap. Work-stations from firms such as Pixar, Silicon Graphics, Dana Computer





and Stellar, which draw in 3-D and living colour, cost anything from $50,000 to $125,000 apiece. Apollo, Sun Microsystems, Hewlett-Packard and Digital Equipment sell simpler versions that produce engineering drawings on monochrome screens in 2-D for around $20,000. Even a modest design office might need a couple of dozen work-stations, setting the firm back $500,000 or more.

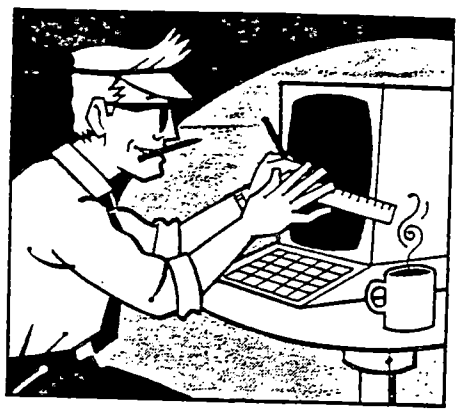
Fortunately, graphics technology is changing fast. In March, Apple Computer announced a beefed-up version of its little Macintosh home computer which, for $7,000, will now perform many of the CAD/CAM design jobs currently done on work-stations costing three times as much. So can one of IBM's latest personal computers. Not surprisingly, Sun has recently slashed the price of the most popular work-station. Any number of powerful little engineering work-stations will soon be available at affordable prices.

If all CAD/CAM had ever done was to telescope design tasks that took weeks or months with pencil and T-square down to just several days in front of a computer terminal, it would have earned its keep. But CAD/CAM does much more. The software used can turn the geometrical data about the widget's shape and function into computerised instructions for driving the machine tools that will make it. So designs whipped up by the firm's engineers to meet, say, a customer's order or a modification to an existing product can be down in the workshop being made within days instead of the weeks or months it took when everything had to be drawn by hand.

Common lingo

One thing is missing: a means for communicating instructions to the machines on the factory floor from, say, the design office and scheduling department. Equally important, the "islands of automation" need to be able to communicate with one another if the flexible machining centres are to be allowed to graduate into CIM and so eventually usher in the factory of the future.

The task itself is not difficult; indeed, many communications networks have been installed in factories around the world. Their one snag is that, so far, they have been proprietary systems that let just individual brands of equipment talk among themselves. Manufacturers want to be able to hook all their machines together, irrespective of who supplied them, into a single gossiping network. And they want to be able to wire up their factories just like telephone companies wire up office blocks—with standardised cables, sockets and switchboards, installed if necessary by



a host of different suppliers, but all conforming to one international convention. Noble aims, but tricky.

Tired of waiting for the International Standards Organisation to come up with a common lingo, the world's biggest user of computerised machine tools, General Motors of Detroit, has imposed its own "manufacturing automation protocol" (known simply as MAP) on the rest of the industry. All MAP is is a set of rules that govern how, in an ideal world, machines of any make should communicate with one another. Nevertheless, such rules, backed by GM's clout in the marketplace, have brought a margin of sanity to the business. Not only have firms making industrial communications and computers begun to embrace MAP, so too have the big users of machine tools in other industries. All told, more than 1,000 manufacturers have rallied to the MAP crusade.

General Motors has a lot riding on MAP. Over the past eight years, it has spent $40 billion on new manufacturing equipment and factories in an effort to turn itself into the cheapest carmaker in America. But the company has gobbled up so much new technology in a hurry that it has left itself suffering from indigestion. Its factories are stuffed with some 200,000 programmable tools waiting to be hooked up to a communications network. In desperation, GM bought Electronic Data Systems (EDS), paying $2.6 billion for the Texas firm and later stumping up a further $740m to buy out EDS's critical founder, Mr Ross Perot, and his associates.

General Motors knows that time is running out; that without MAP many of the benefits of factory automation will be squandered. All its clever high-tech tools will remain deaf and dumb—capable of doing an honest day's work, but unable to use their time intelligently. A year ago, GM started wiring up its first factory, a truck-assembly plant in Pontiac, Michigan, containing 21 types of machines from 13 different suppliers. Since then, it has connected up machines in several more factories to its computers, and has set a deadline of 1990 for having all its new flexible manufacturing plants communicating via MAP to the corporate-planning and marketing departments.

To help it achieve this, GM has forged a strategic alliance with Boeing. While keeping tabs on the 30,000 nuts, bolts, bits and pieces that go into a modern motor car is difficult enough, the problems involved in tracking the 3.5m individual parts used in building an airliner are horrendous. Like GM in the motor industry, Boeing has been forced within the aircraft industry to take the initiative, too.

But unlike a carmaker that cranks out vehicles at a rate of one or more a minute,

building big civil jets involves almost as much painstaking inspection as construction, with a production rate that rarely exceeds half a dozen aircraft a month. Not surprisingly, where GM's approach is to get its "islands of automation" to talk to one another, Boeing's is to build bridges between the "islands of information" that spring up wherever computers are used to automate the flow of documents. For that reason, Boeing calls its communications standard TOP (technical and office protocol).

Because of their different approaches, MAP and TOP turn out to be complementary rather than competitive. Engineers from the two firms have spent the past three years pooling efforts to make the two protocols compatible. They are now five-sevenths of the way there.

Where the slow lane is quicker

Japan is lagging behind in building factories of the future, but it is streets ahead in using the flexible machine tools that will one day go into them

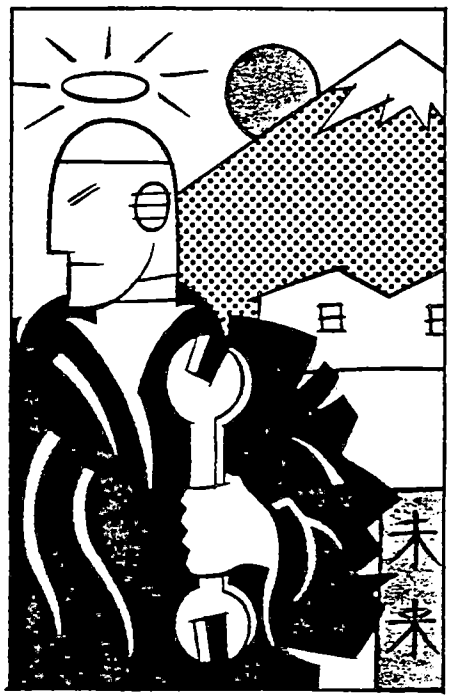
Japan may have few, if any, factories of the future, but it is a bigger user of flexible machine tools than any other manufacturing nation. Since the early 1980s, Japan has been spending twice as much as America or Europe on factory automation. More than half the equipment it has bought have been computerised numerically controlled (CNC) machine tools—one of the essential ingredients for flexible manufacturing. The result today is that 40% of the world's nifty "make-anything" machines are busy beavering away in Japan. More to the point, two out of three of them are in small- to medium-sized firms.

That is not all. Japanese manufacturers are getting more out of their computerised tools than firms in the West. Mr Ramchandran Jaikumar, a researcher at Harvard Business School, reports* that two out of five workers in Japanese factories using computerised tools are engineering graduates who have been trained to use such equipment at university. Similar firms in America have one college-trained engineer for every dozen workers. Compared with American plants, Mr Jaikumar says,

> Japanese factories *have* an average of 2.5 times as many CNC machines, five times as many engineers and four times as many people trained to use the machines.

Moreover, their utilisation rate (the percentage of time the machines are actually cutting metal) is 84%, compared with 52% in the United States. The difference, believes Mr Jaikumar, can be summed up in a single word: reliability.

Reliability is crucial if you want to run a workshop with no men around and the lights turned out. And most Japanese manufacturers want to do precisely that. In one recent survey, no fewer than 18 out of a sample of 60 FMS installations in Japan were found to be running unattended throughout the night. To do this, their designers had anticipated the more obvious glitches, solving production problems long before machines had come grinding to a halt. More important still, the machines themselves had been built stronger than comparable units elsewhere.



How is it that Japanese firms have embraced the FMS part of flexible manufacturing more readily—and more pragmatically—than rivals in the West, and yet have largely failed where American companies have succeeded in mastering the intricacies of CIM? Certainly, the shortage of software skills in Japan has had some effect, though this is not the problem today that it was a decade ago. The answer may be as much historical as cultural.

Forget for a moment the well-oiled hum of production lines at big companies like Matsushita, Toshiba, Toyota or Nissan. Much of manufacturing in Japan takes place amid the clatter of uncovered machinery in back-street workshops, where the ways of organising production have not changed since the days of the Shogun. Locals refer to it as the *seiban* system.

What passes for scheduling here is just a rough list of orders, materials and time slots on various machines. The manufacturer then spends most of his week on the telephone tracking down supplies, while trying to keep his machines running and new orders flowing in. It is the way that "job shops" have functioned everywhere for ages. But job shops live on more vigorously in Japan than anywhere in America or Europe (save perhaps Italy). And inside every Matsushita or Toshiba, despite their modern flexible factories, reigns a long and honoured tradition of jobbing, too.

Unlike their counterparts in America or Europe, most firms in Japan are not bound by fixed ideas about the rules of mass production. Without the strong "Ford-ism" traditions of America and (by imitation) Europe, Japanese production managers view the challenge of flexible manufacturing more as a matter of simply automating a job shop—rather than trying vainly to make a rigid transfer line somehow become flexible. And they have learned to appreciate the value of making frequent incremental improvements to their processes rather than the occasional giant leaps favoured by American firms.

The differences are enormous. For a start, a Japanese firm converting to FMS tooling will spend roughly a third more money doing so than is common among competitors elsewhere. The extra cash goes on equipment to make the changing of dies and cutting edges quicker, the handling of materials easier, warehouse operations slicker, and additional robots visibly everywhere to ensure that, if necessary, the plant can be run unattended. The extra cost is more than paid for by these benefits alone. All the other advantages of unmanned manufacturing—including even higher quality and still lower inventories—are thrown in free.

Toyota-ism means war on waste

"Ford-ism" had its day—though to a lesser extent—in Japan, too. But it is "Toyota-ism" that is propelling Japanese firms into the new era of flexible manufacturing. The reasons go far deeper than the attractions of the fashionable *kanban* method for ordering supplies when—and only when—they are needed. Important, yes, but Japanese managers have been able to see at first hand just what a modest role *kanban* has played in Toyota's overall success.

Essentially, *kanban* (which translates literally as "shop sign") is the same as the American "chit" system for arranging just-in-time deliveries of components. Both are ideally suited for repetitive mass production jobs, where cars, television sets or washing machines are made in large volumes but with little variety. However, when it comes to the flexible factory,

* "Postindustrial manufacturing" by Ramchandran Jaikumar. *Harvard Business Review*, November-December 1986.

neither is actually as useful as the American technique known as MRP (manufacturing resources planning). The only problem with MRP today is that it has become embedded in cumbersome computer programs.

For all their problems, the attraction of just-in-time methods for ordering parts is that they dispense with a good deal of the paperwork. No magic is needed, just a card or chit which travels with a container of thingummies. When the last gets used up, the card is returned to the thingummy supplier where it simply becomes a document authorising the release of yet another batch of thingummies, which are despatched to the customer along with the same (or identical) card.

Two things happen as a result. First, manufacturers quickly learn that the fewer the number of cards in circulation, the less likely are thingummies to pile up at machining stations, gumming up the works and clocking up inventory charges. Second, the battle to reduce the number of cards encourages shopfloor managers to be especially vigilant, hunting down and removing production bottlenecks in their departments. All of which translates into less time and money spent making thingummies.

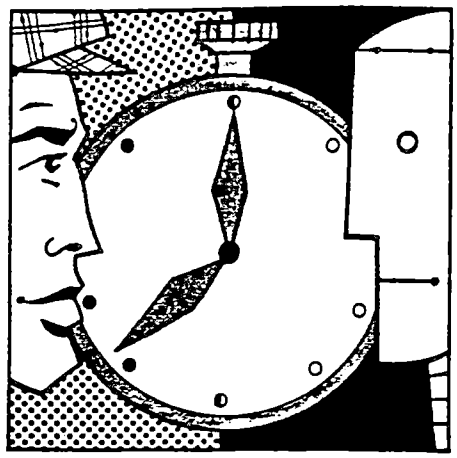
But one of the bigger mistakes outsiders make is to believe that mastering the mysteries of *kanban* is all there is to Toyota's wizardry on the shopfloor. Nothing could be further from the truth. Mr John Hartley, an industrial commentator based in Tokyo, likens it to the tip of an iceberg*:

> *Kanban* represents only about 10% of the whole [Toyota] system, and companies that omit to do anything about the other 90% of their processes are doomed to fail.

In developing their production system, Toyota's engineers went on the warpath against waste. Apart from scrap and overproduction, everything else that did not add value to a product was considered waste—from unprocessed material waiting to be machined to components that had been made too soon. Above all, idle operators were singled out as especially wasteful. With equipment depreciated over time and labour a fixed overhead, idle men were clearly far more expensive to have around than idle machines. Toyota estimated that the cost ratio of men to machines was three-to-one and rising.

So, rule one at Toyota: don't bother "balancing" the machines in a production line (getting them all to complete their tasks within the time taken by the slowest), but focus instead on how workers spend their time. Nowadays, the machines in Toyota's factories are arranged so that operators can handle several at once, even if it means leaving one or two idle while the man moves among them.

* "Fighting the recession in manufacture", by John Hartley. IFS/McGraw-Hill. 1986.



Rule two emerged from studies of the time material spent gathering dust—apparently 60% or more of its total duration in the workshop. Make savings here, said Toyota, of hours or days (say, by using *kanban* internally to abolish storerooms) instead of trying to save seconds by speeding up individual production processes.

Rule three concerned ways of getting a greater variety of parts, quicker, from existing machinery—in short, by reducing the batch size. The biggest problem with most machine tools is setting them up (getting their shaping surfaces or cutting-edges mounted and adjusted) ready to start working on a particular batch of jobs. Because changing dies (the "male" and "female" shapes used to press sheets of metal into contoured parts) can take up to a day to complete, press shops have traditionally been run to provide a month's worth of components for the production lines. The same goes for die-casting machines and forges. Obvious answer: lick the problem of set-up time. Then dies can be changed hourly instead of monthly, batch sizes brought down to dozens instead of thousands, and variety mixed in along the way.

Here, again, Toyota's approach has been characteristically creative. Its engineers redesigned the dies so all of them now have standard fittings and the same height—hence no calibration is needed when they are being installed in a press. They then redesigned the presses, so that today the old dies are slid out while the new ones are slid in. Finally, they invented various quick-release fasteners to save operators from having to tighten dozens of nuts and bolts. Mr Hartley reports cases of dies being changed on 1,000-ton presses at Toyota in ten minutes, compared with at least four to six hours elsewhere. On one particular forge for making bolts, Toyota cut the time taken to change the dies from eight hours to less than one minute.

Imagine the implications of such a production process. The amount of stock carried internally gets slashed from (typically) 30,000 sets of pressings, forgings or die-castings to 1,000 of each at most. Practically all the parts that go to make the finished product (the model of car in Toyota's case) are themselves now manufactured on the same day that the product itself is assembled and moved out of the factory.

For Toyota, that means no more financing of large batches of finished vehicles of different shapes, sizes and colours to meet its dealers' requests. Instead, it holds a small assortment but with a variety wide enough to meet all but the finickiest of tastes—and, for the rare exceptions, the factory can turn out a car of the buyer's own choosing and deliver it to him within five days rather than five weeks.

With that kind of service, few customers have the time—let alone the inclination—to change their minds and go elsewhere. The way Toyota does it, flexible manufacturing is a far cry from any CIM-based factory of the future—but, for all that, it is an awesome competitive weapon.

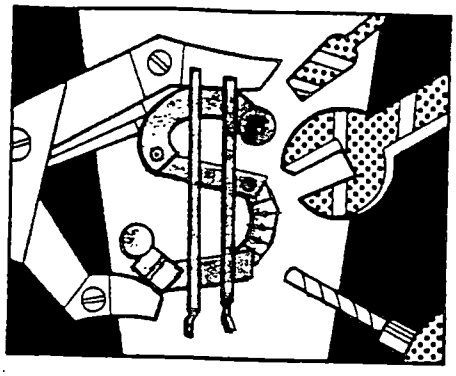
Back to earth with a bump

The "moon-shot" approach to flexible manufacturing gets results—but at a price few of even America's richest companies can afford to repeat

The biggest names in American manufacturing have all been captivated by CIM—and all have been burned to some extent by it. With a wave of the wand, computer-integrated manufacturing promised a way of turning out an array of new products using the same manufacturing plant, at a pace the salesmen were demanding, a quality that was high and yet affordable, and all to the individualised whim of the customer—a way, in short, to roll back the all-conquering Japanese. During the heady years from 1981 to 1986, American firms spent nearly $50 billion installing the tools of flexible manufacturing—almost as much, in real terms, as NASA spent two decades earlier putting a man on the moon.

The biggest of the spenders has been General Motors (GM), starting with the $500m Hamtramck factory it built on a 77-acre bulldozed site on Detroit's east side. The plant contains the largest standing army of robots to be seen anywhere—some 260 articulated contraptions for welding, painting and assembling motor cars, 50 mobile robots for fetching parts from stores, and everywhere computers reaching in and checking the quality of the workmanship. Hamtramck is a technological tour de force, a "factory for the day-after-tomorrow".

Hamtramck's only problem is that it



barely matches the quality and productivity of an aging GM plant at Fremont in California, where the world's largest motor manufacturer has a joint venture with Toyota stamping out copies of compact Japanese cars for the American market. Fremont does it all without fancy automation, just a lot of painstaking Toyota-style management.

Buick City at Flint in Michigan has also been a bit of a disappointment for the gurus of high-tech manufacturing at GM. The $400m factory has all the ingredients for success—including flexible tooling that needs only a third the inventory of a conventional assembly plant. Yet it has taken twice as long to get cars rolling off the line, and many of its touted benefits are beginning to look somewhat illusory.

All of which has brought GM up short. It is now having serious doubts about how much technology to use in its Saturn project, a bold $3.5 billion attempt at Spring Hill, Tennessee, to rewrite the rules of making motor cars. Meanwhile, the firm has started laying off middle managers and engineers, and has been cancelling contracts with equipment suppliers. It has even axed $88m-worth of orders for new robots from GMF Robotics, the 50-50 firm it established in 1982 with Fanuc of Japan to supply its factories with the latest carmaking automation.

Much the same tale is whispered at General Electric (GE), which spent $600m on a pioneering CIM plant in St Louis for making dishwashers. Its factory of the future raised productivity by nearly a third, cut warranty calls by a half and boosted GE's share of the dishwasher market in America from 31% to 43%. But many GE managers believe the price was far too high. On the drawing-board at GE are blueprints for a further six flexible appliance factories costing a total of $1 billion. They are unlikely to use anything like as much automation as GE's pride and joy in St Louis.

Even IBM has had its trying experience. At its new $350m typewriter factory in Lexington, Kentucky, some 2,000 people can now turn out 1.4m units a year, where 6,000 used to make only half that number. The new typewriters are made from components that are only 15 minutes old rather than 90 days; are so reliable that they need servicing roughly once every four years instead of annually; and cost $1,000 less than the Selectric models they replace. Dr David Ellerman, IBM's automation expert on the Lexington project, says the plant is so flexible "it could build a couple of hundred IBM product lines—even video recorders, microwave ovens, cameras, attaché cases."

Of course, IBM has no intention of muscling into home appliances or consumer gadgets. Nevertheless, it is having trouble finding enough things to keep Lexington busy. Critics say that IBM over-automated; that the plant is nowhere near as flexible as claimed; and that the computer company got nothing like enough manufacturing bang for its buck. IBM admits that, if it had to do it all over again, it would do it differently.

And it has—on several occasions. The flexible factories that IBM has started sprinkling across America and Europe attempt to be nothing like as clever as its Lexington showcase. Moreover, to ensure that they always have plenty to do, the new automated plants in Texas, Florida, California, Scotland and Hampshire tend to make whole families of products—such as printed-circuit boards, personal computers and information-storage devices.

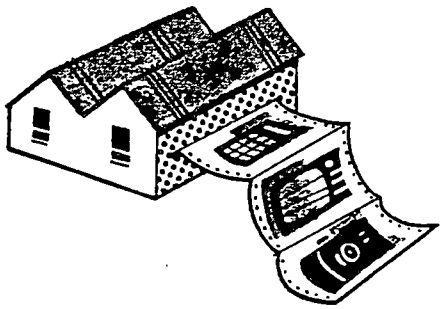
America's largest dozen or so firms that have embarked on costly CIM-like adventures have learned that the "moon shot" approach certainly gets results and provides useful experience, but at a price that few, if any, of them can afford to repeat. For a few brief years, America's brave high-tech form of manufacturing flared brilliantly across the headlines. Lately, however, it has fizzled back to earth—and the big guns of manufacturing in the United States are a good deal wiser for it.

It helps being poor

Other American firms, lacking the resources of a GM or IBM, have kept their feet more firmly on the ground. Allen-Bradley, Caterpillar, John Deere and a couple of dozen more have built successful CIM plants without the heartache or crippling expense. Despite its limited resources, Chrysler is believed to be the best of Detroit's big three at flexible manufacturing. No mention is made of how much it has really spent on its Sterling Heights factory, but it carried out 900,000 man-hours of training before opening the CIM plant in 1984. The result today is that Chrysler can produce two new models a year instead of one every four years.

A characteristic of these American manufacturers of more modest means is that they are neither "visionaries" nor "ostriches". People in the trade call them "evolutionists". All of them have been nibbling away at computer-integrated manufacturing without committing themselves to overly ambitious projects. As a rule, they have tended first to computerise their machine tools, creating "islands of automation". Next, they have streamlined their scheduling departments, slimming down the wadges of bumph they produce. Only then have they linked the two departments together, so the machines receive their instructions and materials precisely when, and only when, they are needed.

Past master at this step-by-step approach is Hewlett-Packard (HP). Within its own business of making test equipment, instruments and computers for the engineering community, HP has a broad diversified mix of products, many being made in small numbers—a natural case, if ever there was one, for CIM. Since 1983, HP has been



consolidating its manufacturing into a handful of highly flexible plants specialising either in a group of related products (printed-circuit cards, for example) or a particular type of technology (surface-mounting of components).

The interesting thing is that improved competitiveness at HP has come not just through eliminating duplication and waste. In consolidating its business, the firm has been forced to scrutinise its own manufacturing processes in the minutest of details. "We found there were lot of informal procedures which were not supposed to be there," says Mr William Boller of HP's manufacturing-systems group. "There's a lot of 'fixing' done by people on the line which never gets shown on any organisational chart." It is those kinds of "unofficial" processes that have to be replicated if CIM is to work effectively.

Hewlett-Packard advises companies wanting to go the CIM route first to learn how their factories actually function, not how they are supposed to. The next job—long before placing any orders for robots, flexible tools or fancy computers—is to simplify all the procedures down to their bare essentials, concentrating on just those processes that add value to the business. The firm then needs to ask itself what is the minimum amount of information the value-adders (whether men or machines) need to accomplish their tasks. "The root of all evil," says Mr Boller, "is complexity."

Honest self-analysis like this can save piles of cash. Often, it results in very little automation going into the workshop itself. Instead, the heavyweight procedures like MRP (manufacturing resources planning) for specifying parts, purchasing materials and scheduling the work get ruthlessly pruned. The only tasks that are then automated are just those clerical jobs generating information that is absolutely essential.

At a stroke, all those middle managers (purchasers, specifiers, expediters, and so on) are no longer needed. And the biggest single source of overhead costs in most western factories (rarely less than 40%) shrinks dramatically. In America at least, the lights are being turned out faster in the office than in the factory.

Too little too late?

Many European firms seem to look on factories of the future as intellectual curiosities best left for researchers to study with taxpayers' cash

Europeans seem to enjoy the intellectual challenge of re-inventing the wheel. They are pursuing something similar to CIM but prefer to call it AMT (advanced manufacturing technology). Where a decade ago the Pentagon played midwife to CIM in the United States, Community officials in Brussels are now hoping to play wet nurse to flexible automation in Europe. They are spending millions trying to prevent industry's response to this vital new technology from being once again too little too late.

Under its Esprit programme on information technology, the EEC has spent $120m of public money since 1982 developing ideas for the factory of the future, and is now getting down to serious business with a proposal for CIM research totalling $1.3 billion over the next five years. On top of this, the Community plans to pour more than $900m into communications research under its Race programme, and $140m has been allocated to its Brite programme on industrial technologies. Then there are the national efforts on computer-integrated manufacturing run by individual European governments. Britain's, for instance, comes under the government's $450m Alvey programme.

Doubtless, all this laboratory research is contributing mightily to the store of useful knowledge about CIM. But, perversely, it seems also to be distracting European manufacturers from getting on with it. Few firms in Europe outside the defence industry are making anything like the enthusiastic commitment to flexible manufacturing that is now so evident throughout Japan and increasingly so in regions of the United States.

There are, to be sure, flexible manufacturing plants in Europe which are as advanced as anything to be found in America or Japan. Olivetti's factory at Scarmagno in northern Italy produces a varied range of personal computers at a rate of one every 15 seconds. The firm's Zincocelere plant, equipped with the latest CIM-like tools, makes a variety of printed-circuit boards as cheap as anywhere in Asia.

At Rolls-Royce's aero-engine plant at Derby in Britain, flexible manufacturing has turned a workshop making the crucial disc components that prevent jet engines from falling apart into a vision of the unmanned future. The $6m investment, which paid for itself in 12 months, boosted productivity by 40%, slashed work-in-progress by two-thirds, and reduced the time taken between receipt of an order and delivery from six months to six weeks.

That said, there are only a dozen or so installations in Britain that can be classed as even flexible manufacturing systems (FMS). None is equivalent to any of the "lights-out" type of CIM plants seen increasingly in the United States. Estimates vary, but the total number of factories in Europe with some form or other of flexible manufacturing cannot be more than 50. Japan, with half the population, is now installing that number of FMS units annually.

Like computer companies in America and Japan, Britain's ICL is gearing up to sell manufacturers some of the software packages that will help make CIM a reality. It is looking at a market, not of today, but of five years down the road. It wants to see the various flexible manufacturing techniques settle down first, so it can develop programs that will appeal to at least 80% of all industrial users. A failure of nerve? Maybe. But no more so than the lack of imagination among the mainstream of Europe's manufacturers.

Despite having one of the most original research programmes on CIM anywhere, Britain's biggest engineering group, General Electric Company (GEC), reflects the current mood of scepticism among manufacturers in Europe. By all means start developing a strategy for computer-integrated manufacturing, GEC's head office tells its managers; even recruit some of the right kind of people. But GEC would prefer its subsidiaries not to splash out on flexible manufacturing for the time being. In Europe, such thinking is not unusual. Little wonder that Japanese firms think their European rivals have given up the fight.

If it ain't broke, don't fix it

Many manufacturers making a living today are understandably leery about splashing out on high-tech factories for tomorrow. There are good reasons why they should hold back—and better ones why they can't afford to delay

The showcase factories of the future have attracted their share of notoriety because of the cost and trouble involved in getting them up and running. In reality, however, firms need not spend more than $5m or so to gain many of the benefits of switching a factory over to CIM-based production. Sheer inertia is probably the main reason why mainstream manufacturers, in Europe especially, have not embraced the flexible factory with quite the same gusto as their Japanese and (increasingly) American competitors.

Certainly, CIM is something not to be entered into lightly. To start with, nothing short of a total overhaul of the company's strategy has first to be undertaken, involving many man-years of managerial effort. The rule, learned painfully over the past seven years, is "plan from the top down and implement from the bottom up". This requires managers to ask themselves searching questions about what products they expect to be making in five years' time, which technologies will they be using, who will be their competitors, how fast and at what price will their fancy new flexible plants be able to respond to signals from the marketplace. Such questions cause heated boardroom arguments.

Companies also need to be ready to head off countless little turf wars. When implemented properly, CIM requires all departments to rely on, and contribute to, the same database of information. Bulldozing its way across office and workshop boundaries, CIM has an immediate impact on the way people do their jobs, even on the titles they give themselves. Nasty little booby traps here for the unwary manager.

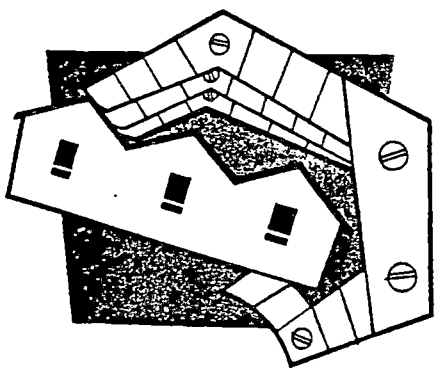
Firms also face the frustrations of trying to get the various pieces of CIM equipment to communicate with one another. There are simply not enough communications engineers, not even at General Motors, Ford, Boeing and IBM, with the experience of installing MAP networks and getting them humming sweetly. Meanwhile, the computer software that makes MAP tick continues to evolve. Manufacturers are currently working with version 2.1, but will have to upgrade to version 3.0 in little over a year's time.

It is hardly surprising, then, that smaller firms who have taken a look at MAP gasp, not just at its cost (twice as much per

connection compared with local area networks used to hook computers together), but at its complexity, too. There have been requests (loudest in Britain) for a simpler, stripped-down version capable of serving most of the needs for the majority of users.

Yet others complain that MAP is not powerful enough. Certainly, it is incapable of telling a smart robot (one with eyes, ears and a sense of touch) to take immediate corrective action should an overhead crane accidentally drop a workpiece on a machine tool being served. The cables MAP uses, and the electronic beeps coursing through them, are not up to the job of conveying visual pictures in "real time".

Nor are the communications problems restricted to the shopfloor. Design engineers using CAD/CAM work-stations are having trouble sending their clever geometric patterns from one maker's screen to another's. Some of the bigger users of CAD/CAM have been trying to bang heads



together among suppliers, hoping to get them to adopt a universal language, any language, even the plagued IGES (initial graphics exchange specification) promoted by the National Bureau of Standards near Washington.

The French have, at least, managed to get their own graphics protocol called SET (*standard d'exchange et de transfert*) adopted by Airbus partners to swap design information between aerospace plants in France, West Germany, Britain and Spain. And the German motor industry is slowly getting its own CAD/CAM language, VDA-FS, accepted among components manufacturers around Europe.

With so many technical problems still to be resolved, the wait-and-see attitude towards CIM among smaller manufacturers is easy to appreciate. One other reason—the soaraway yen—is a good deal harder to understand. It is common knowledge that even when the yen was languishing at 225-250 to the dollar back in the early 1980s, Japanese exporters had taken the precautions of tuning their factories so they would be able to export profitably at Y180 to the dollar. With the exchange rate around Y140 to the dollar, the likes of Toyota, Matsushita, Hitachi, NEC, Sony and Toshiba have been cramming the latest pieces of intelligent automation into their factories at home so they will be able to carry on exporting profitably when the yen is as high as at Y130 to the dollar—or higher.

Western manufacturers who think the rising yen has given them a break are in for a surprise. Within six months of the meeting of the Group of Five at the Plaza Hotel in New York in September 1985, Japanese companies were declaring paper losses (well before the impact of the rising yen had even begun to feed through to their balance sheets) as they hurriedly wrote off existing plants and hustled forward plans for a new generation of "lights out" automation. Those flexible factories are now being switched on all over Japan.

Upside-down accounting

Factories need a new brand of book-keeping if the real costs and benefits of flexible automation are to be tracked properly

The first mistake managers tend to make when planning a factory of the future is to think of the number of jobs they can save. Then comes the unpleasant surprise: investing in flexible automation may eliminate grunt jobs on the factory floor, but it usually requires more skilled workers—and costlier ones at that.

The mistake is to look just at the direct costs. When everything is added up properly, labour accounts for between 5% and 15% of manufacturing costs, no more. There is little point in tearing up an existing factory to build a costly new one if the sole objective is to knock a few percentage points off the payroll bill. Justifying an investment in CIM requires a careful scrutiny of overheads and a look at some of the intangible benefits that can accrue.

The trouble is that book-keeping methods have not kept pace with the times. For years, cost accountants in manufacturing dealt with mature products based on stable technologies. Their rules worked well in old-fashioned factories where mass-production was the order of the day. But in a CIM plant—where the crucial factors are quality, variety, response and speed of delivery, and how best to use costly equipment—these rules are as out of place as a sledgehammer in a microchip works.

Over the generations, accountants have forced managers to focus single-mindedly on means of minimising direct variables like labour, materials and energy. They get it upside-down when they do the same for the flexible factory. Here it is fixed costs like plant and equipment, not variable costs, which are now the dominant feature. Dr Alfred Mirani of IBM's European CIM centre in Munich reckons that fixed costs account for nearly 70% of a flexible manufacturer's total bill.

Nor have cost accountants come up with ideas of how to put cash values on indirect benefits—such as better product quality, or the flexibility to plunge into a market swiftly and then manoeuvre adroitly to snatch opportunities and fend off threats. Lacking anything more rigorous, companies getting into CIM have tended to make their investment decisions on leaps of faith, acts of hope and sheer imagination.

And so CIM exists uncomfortably in an environment where 80% of the accounting effort goes on tracking 20% of the activity; where all efforts are geared to cutting costs rather than boosting revenues. How to find a more rational way of gauging the costs and benefits of CIM? Try taking a leaf out of Mr Michael Skidmore's book.

Mr Skidmore is boss of Altek Automation, a small firm making CIM equipment in Britain. He admits* it is hard to justify using smart automation like robots to replace unskilled people doing light-assembly jobs, especially in low-wage Britain where rates for such work run to no more than £3 ($4.85) an hour. Given a payroll tax of 9%, absenteeism of typically 5% and a reject rate of another 5%, wages this low make it difficult to justify installing a $50,000 piece of automation when traditional accounting methods are used.

The reason is because only marginal costs are considered. Certainly no account is taken of the robot's flexibility—its "reconfigurability". Automation like this can assemble a variety of products in one configuration, and then be reprogrammed at little extra cost to handle a quite different set of goods.

So get the sales department to calculate by how much the product's price would have to fall if its market share were to be doubled. Then, from the new (higher) level of output—and ignoring for the moment the number of extra employees needed—work out a fresh (lower) figure for the gross profit margin. Finally, estimate the manufacturing cost from the existing labour cost plus the cost of the robots needed to make up the difference between the old and the new levels of output.

The best thing about doing factory economics this way is that it forces people in marketing, design and production departments to come up with numbers that allow senior managers to undertake (perhaps for the first time) a genuine analysis of the company's real costs. This is a lesson that

* "How robots can earn their daily bread", *The Engineer*, August 21-28, 1986.

Japanese manufacturers have long since learned. By using this kind of approach, they have no difficulty in justifying investments in intelligent automation like robots, CNC machines or even FMS installations. In fact, it becomes a way of life—a means for maximising market share, and hence the revenue that can be earned from a firm's existing workforce. The rest of the industrial world still tends to view such investment as a way of axing jobs in order to reduce costs. Is it mere coincidence that many Japanese manufacturers have been expanding, while the majority of western firms struggle to hang on to their place in the global market?

Plan, don't run

The future belongs to manufacturers who learn to plan their new flexible factories. With wholly different approaches, Japanese and American firms are learning fast. European firms seem to think they can wait and see

How, then, to reduce the pain of creating a factory of the future? Manufacturers who have done so swear that the longer the gestation the better. They talk of "birthing", the mental and physical preparation that reduces the agony by removing the mystery and uncertainty. Above all, they say, have a strategy—know precisely, and in the simplest of terms, what it is you want to do. Meanwhile, train, train and train everyone again—none more so than the middle managers who have most to lose, most to fear, and are most likely otherwise to go round sticking spanners in the works.

The most common mistake is to think of CIM as a set of tools, an off-the-shelf solution to solve what is really (though rarely admitted) a problem of poor management. Forget all the consultants' hype, CIM is nothing more than an attitude of mind, a dedication to a few worthwhile principles—like simplicity, collaboration, quality and zero-defects. In IBM's view, "the objective [of CIM] is not total automation, but running a profitable business."

Manufacturers who take pains to implement their CIM equipment carefully embark on a virtuous cycle. The first thing to go is waste. Firms get a nasty shock when, for the first time, they start getting proper information from a computerised network on the amount of scrap they are producing (aircraft manufacturers are notorious scrap merchants) along with the cost of all the rework incurred. This concentrates the mind of production engineers remarkably.

The next thing to be abolished is sloppiness—in engineering tolerances as much as management control. With up-to-the-minute information on how tools in the machine shop are wearing as they grind away at making parts, the firm's designers can start specifying tighter fits for the components—confident that worn cutting-edges will be replaced automatically and whenever necessary, rather than perhaps at the end of a shift or during maintenance at night. With this, a level of ultra-precision machining—known once only to lens grinders and watchmakers—is becoming available on the factory floor. In turn, ultra-precision is eliminating yet more waste and improving the actual performance of products.

All of which adds up to more for less. The product's higher quality in terms of its fit, finish and performance actually comes at a lower price. The savings accrue from reductions in the amount of scrap, rework, service calls and warranty schemes that formerly went into making up for shoddy workmanship.

In cases where CIM has backfired, the company has usually been in too much of a rush to get its new flexible factory up and running. And disasters have proved to be not so much a matter of too much technology, but rather too little of the right sort. Integrating different types of computers and machine tools is the easy part; integrating workers with differing skills and backgrounds is far harder. Psychologists are only just beginning to understand the social technologies involved.

When CIM comes in, out go whole offices of people who formerly spent their lives ordering parts and materials and scheduling the workload of various machines. Even in Japan, where overheads are typically only half as much as in Europe or the United States, medium-sized firms switching to flexible manufacturing say the number of people in the engineering department is halved (from, say, 35 or so to around 16), but clerical grades in the production department get slashed by about 90% (from 60-plus to fewer than six). This means engineers begin to outnumber production workers—in many cases, by three to one. The main preoccupation of the business then becomes, not running the plant, but planning it.

Automate or liquidate

Japan has a competitive advantage here. It graduates annually twice as many engineers per 1m people as America, nearly three times as many as Britain or France. In company after company in Japan, says Mr Ramchandran Jaikumar of Harvard Business School, systems engineers with a thorough knowledge of several disciplines have been decisive in bringing flexible manufacturing to fruition. Contrast that with factories in the West, where managers spend so much time trying to solve routine problems concerning quality and delivery that they scarcely have any time to think about how to improve the production process itself.



Source: OECD

And it shows. Mr Jaikumar's research on global competitiveness points to alarming trends in American manufacturing—and, by inference, in Europe as well. In a recent issue of *Harvard Business Review*, Mr Jaikumar wrote:

> With few exceptions, the flexible manufacturing systems installed in the United States show astonishing lack of flexibility. In many cases, they perform worse than the conventional technology they replace. The technology itself is not too blame; it is the management that makes the difference.

Compared with Japanese FMS cells, those in American plants produce only a tenth the range of different parts. European plants, at their present stage of evolution, are no better.

Firms on both sides of the Atlantic are in the process of catching up with competitive manufacturing. Mostly, they are still striving for higher quality, while their Japanese rivals—having licked the excellence issue—have moved on to other problems in search of a new competitive edge. Manufacturers in Japan worry instead about how to live with *endaka* (the 70% stronger yen) by lowering prices further and bringing out new models faster and more frequently—in short, by manufacturing more flexibly in order to carry on shipping goods abroad when the yen has hit 130 or fewer to the dollar.

But the Japanese are not ten feet tall. The strength of Japanese manufacturers today is rooted in their traditional *seiban* approach to running a job shop. Up till now, its limitations have, ironically, been a blessing. Scheduling of materials and machines is done in the production manager's office on pieces of foolscap pinned to the wall. No reams here of printout spewed from MRP-II programs running through the night on big mainframe computers.



Cleaner than a hospital



Tidier than a workshop

Lacking the software, Japanese firms have been forced in the past to think more creatively, to be more elegant, to reduce their scheduling requirements to the bare essentials. But there are limits to how far the *seiban* form of production control can be pushed. Already CIM is revealing glaring inadequacies in the one-side-of-foolscap approach. Meanwhile, American firms at the leading edge of manufacturing technology are learning a trick or two about getting computers to produce just the essential elements, rather than their present overwhelming volumes of information for their planning processes. Hewlett-Packard preaches the gospel: "Learn first to do what the Japanese do, then automate it."

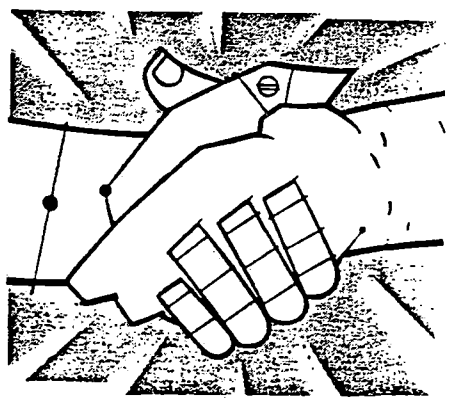
And never discount the genius of the defence industry in the United States. Put aside $500 hammers, $1,200 toilet seats, fiascos like the $4.5 billion spent on the Divad gun, even faulty O-rings that brought the Challenger shuttle low, as lunacies tolerated or (worse) mandated by government agencies. If the rest of manufacturing in the United States had enjoyed the benefit of, say, the American Air Force's "Get Price" or "Competition Advocacy" programmes and learned to work to much the same overall levels of quality assurance, performance, delivery and (yes) even price, the world today would be watching television on sets made by Sylvania, Zenith and RCA, surrounded by appliances from Frigidaire, GE and Westinghouse, and Detroit would be exporting cars to Japan.

America's high-tech automation firms that helped transform the country's defence contractors into the most flexible manufacturers anywhere are now busy selling their expertise to the rest of American manufacturing. Hewlett-Packard reckons that 96,000 factories in the United States are currently in the process of installing CIM in one form or another. In a year or two's time, many of them will become global forces to be reckoned with; some will no doubt conquer the foreign competition and become the new market leaders.

Sadly, Europe has nothing to compare. Carmakers in West Germany, France, Sweden, Italy and Britain have their "islands of automation". So does Europe's handful of world-class aerospace and computer firms. But lacking the imagination of Japanese manufacturers or the resources of American rivals, European firms tend to put their faith more in the Community's multi-billion research programmes like Esprit, Race and Brite. Even Fiat, the Italian motor manufacturer that pioneered some of the world's most advanced carmaking automation, is currently lobbying Brussels for a similar "catch-up" programme in CIM research. Throughout Europe, the loudest call to be heard from the manufacturers is for research handouts.

Yet nowhere else in the world could CIM have such an immediate—and more readily justifiable—impact on manufacturing. Nor are government bribes necessary. European industry is sitting on all the cash it needs to implement the latest in flexible manufacturing. Where? Gathering dust on shelves in its warehouses in the form of excess stocks and as work-in-progress on its factory floors. British industry alone is reckoned to have the equivalent of $25 billion tied up in inventories. If only a quarter of that were released through just-in-time scheduling, British firms could buy all the CIM equipment they need for the next couple of years.

When implemented correctly, just-in-time scheduling slashes inventories by, not 25%, but more like 75%. Japanese manufacturers realised that sooner than most. American firms have been getting the message for four or five years now, and are moving on from mere flexible forms of production to fully computer-integrated manufacturing. Meanwhile, the choice for the majority of mainstream manufacturers in Europe is becoming chillingly clear: either they automate using the flexible new tools that lead to CIM, or many will be left with little choice but to liquidate.



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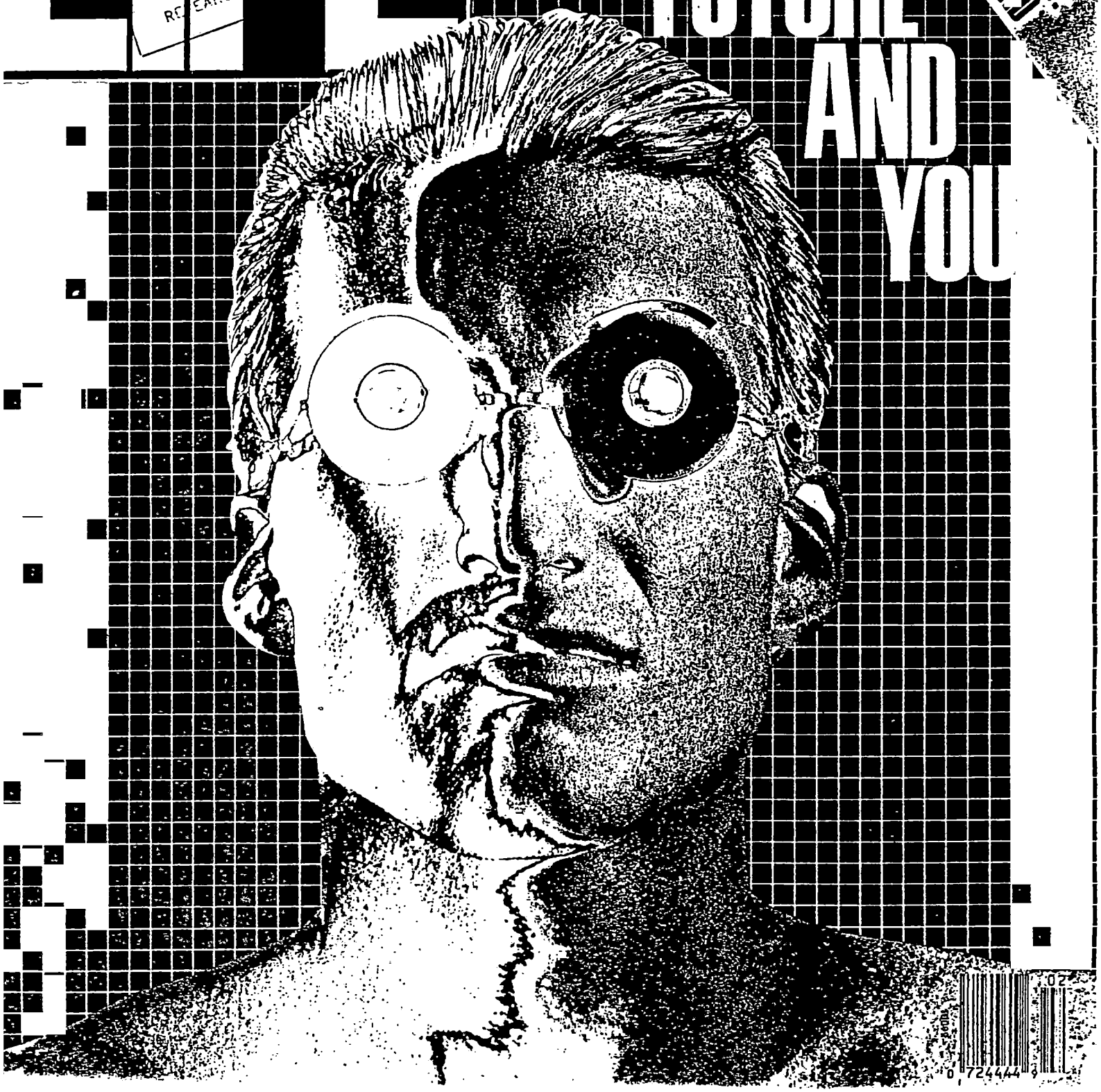
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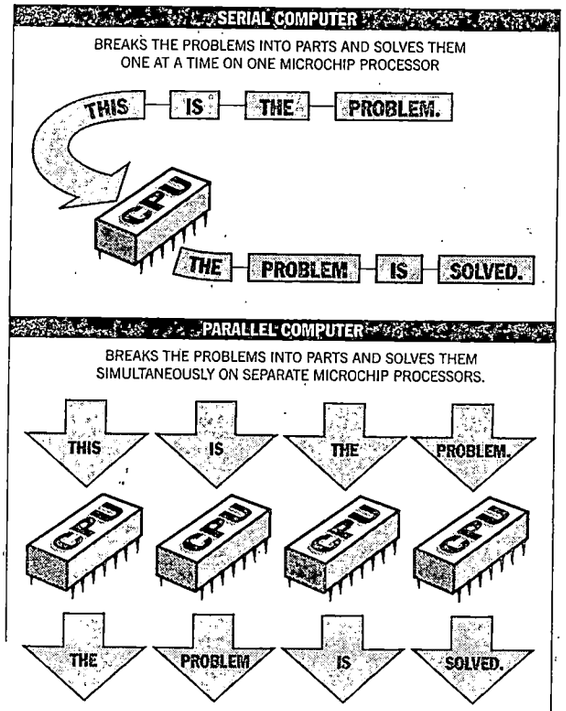
Japanese sun
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The Next Great Leap in Speed

'Massively Parallel' Systems May Meet a Pressing Technological Need



COMPUTING'S 'GRAND CHALLENGES'

Massively parallel computers are needed, scientists say, to understand various phenomena by modeling:

- The atmosphere, land and water in enough detail to forecast the weather more accurately.
- Larger-scale phenomena to predict global climate change.
- The behavior of particles in a turbulent flow to predict the dispersion of pollutants and understand combustion.
- How electrons and other subatomic particles behave in semiconductors and superconductors.
- How the brain integrates input from the eyes to create an image.
- The interactions of molecules in cells that perform various functions of life and disease.

By Curt Suplee
Washington Post Staff Writer

Next month in Pasadena, technicians will throw the switch on what will be—for a while, at least—the fastest computer ever built. If the new machine works as advertised, it will set a world record for peak speed: 32 billion operations per second. That's more than 10 times the number of heartbeats in an average human life, compressed into the time it takes to sneeze.

Yet even at its stupendous best, the $27.5 million Touchstone Delta System to be unveiled May 31 at California Institute of Technology will be sluggish by the increasingly demanding standards of modern science. It is, however, the latest stage in a national initiative to boost computing speeds by a factor of 1,000 within five years by exploiting a design called "massively parallel processing," or MPP.

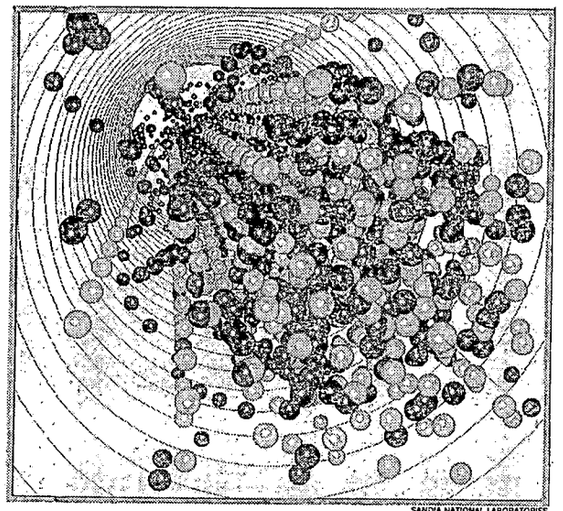
This is a system by which hundreds or thousands of microprocessor chips perform separate operations simultaneously. In most conventional computers, just one microprocessor does all the work, one step at a time.

As recently as 1987, MPP was considered downright radical. Even 18 months ago skeptics were preponderant. "But we've gone through this credibility transition in the last year," said Danny Hillis, founder of Thinking Machines Corp., an MPP pioneer. "Now, finally, people have understood how to use it."

For many researchers, that can't happen too soon. Repeatedly in the history of science, the grand march of inquiry has been stalled until new technologies—from telescopes and microscopes to X-rays and semiconductors—arose to make new visions possible. Computer power is now at just such an obstructional juncture.

In a dozen fields—including climate modeling, genetic research, aerospace-vehicle design and protein synthesis—computer simulations have grown so accurate that they can replace much of the tedious and costly process of experimenting with real objects. For example, designing an airplane involves plotting the airflow around surfaces of varying shapes. These experiments, formerly conducted on models in wind tunnels at huge cost, can be done very accurately on existing computers. But they require hundreds or thousands of hours of running time. On a computer a thousand times more powerful, however, "a complete numerical simulation of an aircraft in flight could be performed in a matter of hours," computer scientists Peter Denning and Walter Tichy wrote in Science last winter.

Similar difficulties plague research on better fuels. More than 400 chemical processes occur in internal combustion engines, yet today's computers can handle no more than 10 in simulations if they are to do the job in a few hours.


SANDIA NATIONAL LABORATORIES

An example of a simulation of electron beam propagation produced by using a massively parallel version of a Sandia National Laboratories computer code.

A Teraflops Contender

Years ago, the federal High Performance Computing and Communications Program, a multi-agency task force, identified these problems and other "grand challenges" as "critical to national needs," and determined that computers capable of 1 trillion operations per second would be required to solve them. "Then they had to look around for the design that was going to be able to deliver that," said Larry Smarr, director of the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign. "And the only possible architecture is massively parallel."

Every computer operation involves identifying a unit of data and then doing something to it: For example, a program might ask a computer to find every letter "g" in this article and then make it "gg."

In a traditional "serial" computer, this would be done by one central processor or master chip, which would call up one word at a time, in series, out of the computer's memory. The chip would examine each word for the presence of a "g," double the letter if it found one, and then store the result in its memory before fetching the next word. Conventional supercomputers speed that process by cutting the time between operations, using several processors and devising supercooled or superconducting connections; but basically they employ the one-item-at-a-time principle.

If, instead, the "g-doubling" task were conducted on an MPP system, each of the 1,100 or so words would be assigned to its own processor. Each chip would receive the same instruction from the software, and all the words would be examined and processed at the same time. Ideally, such a device would perform the task 1,100 times faster than traditional machines. It might also cost less, because the processors can be simple and relatively slow (as individuals) compared to the high-speed multi-use devices in traditional serial systems.

The Pasadena behemoth uses a variation on this design, whereby each processor can follow several sets of instructions on several data sets. Built by Intel and funded by a consortium including the Defense Advanced Research Projects Agency, Touchstone will start small, with an array of 528 processors. Even so, it is expected to beat the cybernetic socks off the latest Japanese dreadnought, NEC's SX-3, peak-rated at a mere 22 billion "floating-point" operations per second. In the trade this is known as 22 gigaflops.

Intel expects Touchstone to be a teraflops—capable of a trillion floating-point operations—contender eventually, though no one is quite sure what that might require. Some scientists believe it could take as many as a million processors. But Hillis, whose firm has contracted with DARPA to develop a teraflops machine by the mid-1990s, thinks it may be accomplished with as few as 65,536 processors—the number used now on the company's massively parallel Connection Machine.

Seeking Synchronicity

"The biggest obstacle is not getting the sheer computation power," Hillis said, "but getting the processors to communicate and coordinate." Because those devices have to exchange information constantly in perfect synchronization, he said, a teraflops machine "will require more communications connections than there are in the entire U.S. phone system put together."

Moreover, MPP requires researchers to re-conceptualize their problems for parallel architectures. And programmers have to translate those ideas into software. Until recently these problems seemed practically insoluble; but that has changed. New MPP companies are springing up, and venerable firms are switching over: Supercomputer market leader Cray Research and Digital Equipment Co. have begun work on MPP systems. In February, Sandia National Laboratories in New Mexico, a world leader in MPP research, announced it was converting its key programs to massively parallel form.

Meanwhile, a growing number of experts now agree with Denning and Tichy that "the new breed of massively parallel machines will, in the long run, have an impact as profound as microcomputers."

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William Raspberry

WPOST 3-10-91

A Simpler Life

Americans are either in the throes of a materialistic orgy in which "acquiring possessions has become an end in itself" or else we are witnessing the beginning of a return to the simple, values-driven life.

It depends on which magazine you read.

Bruce Baldwin, a psychologist writing in the April issue of the USAir magazine, sees an America in which our "wants" and "needs" have become confused, things substitute for sounder values, and possessions define self-esteem.

Time Magazine's Janice Castro, on the other hand, sees us as emerging from "a ten-year bender of gaudy dreams and godless consumerism" and, at last, "thinking hard about what matters" in our lives: family, friends, rest, recreation and spirituality.

So which is the real America? Maybe both. There can be no doubting Baldwin's contention that easy credit and persuasive advertising have combined with the rise of dual-income families to produce a culture in which adequacy no longer suffices: not accurate watches, attractively serviceable raincoats or reliable cars with decent gas mileage, but Rolexes, Burberrys and Mercedes Benzes.

We talk "quality," but like the inner-city kid whose absurdly expensive sneakers and starter jackets have us shaking our heads in dismay, we buy things as much to let our peers see how well we're doing as for the efficiency, beauty and durability of the things themselves.

But Castro says we're doing it less. Signs of a revolt against crass consumerism constitute a pattern "as genuine as Grandma's quilt," she reports.

Successful men and women are leaving their high-powered, well-paid jobs for humbler work that gives them more time with their families; wives are abandoning careers to take up homemaking. Consumer credit fell by 0.6 percent—$342 million—in December, and a whopping $2.4 *billion* in January. Domestic beer, mixed-breed dogs, family reunions and voluntarism, says Castro, are replacing look-at-me spending. The '90s may come to be known as the "We Decade."

Cynics might tell you that our down-shifting has other, less noble, causes, including a recession that has people either out of work or else nervous about their job security. Part of the trend Castro sees may be pure fad, as empty of deeper meaning as earlier shifts to jogging, oat bran and lite beer. Maybe we're finally starting to recognize subliminally a fact that seems to have escaped our consciousness: that the 1980s were a period of downward mobility—declining real income—for most American families.

But it's possible to doubt Castro's "humble makings of a revolution in progress" while at the same time hoping she's right. Rampant materialism, as Baldwin notes, has costs beyond the erosion of bank accounts.

"It can seriously affect an individual and a couple's ability to live a happy and healthy life together. . . . In many distressed marriages and dysfunctional families, couples have a myriad of 'things.' What they do not have for one another, nor for the children, is time to enjoy life together, to talk and to share interesting experiences." Castro says it's all changing. She cites a Time-CNN poll that found 69 percent of the respondents wanting to "slow down and live a more relaxed life." A majority complained that earning a living takes so much effort that it's hard to find time to enjoy life. And 89 percent cited the importance of spending time with their families, percent wanted more time for pers al interests and hobbies, while only percent rated it important to keep with fashions and trends.

Maybe the trend she cites is r but Baldwin's description seems c er—uncomfortably so—to home, a lot of couples I know (including at the address on my tax retu could do worse than take his advic

"Begin a series of discussions v your spouse. Ask yourself questi and then answer them. For exam 'Why are we living like this? Wha we really want out of our life tog er? How are we going to get th What is really fulfilling in this sl life we have?' " I'd be surprised if psychic and spiritual welfare of children didn't figure prominentl the answers, or if the couples faile discover a mutual interest in li simpler pleasures.

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- Kurzweiler on blind
- Cal Tech grads winning

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- first of everything
- frontiers
- sci/tech books
- date books

CALTECH
- any STS award winners
- student projects - humane
-

- jokes
- famous alumni; Nobels, etc.
- popular activities
- facilities on campus

THE WHITE HOUSE
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Bus Week
Spectrum cover article

Fortune
early this year
- trends to come -
electronic future

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Gilder – Beyond Television

Policy Push

1) Set infrastructure: take advantage; let give incent to P.S. to take advantage; let market forces. Already we have?

already
* deregs: telecomm
- diss barriers
high perf computing initiative
[look in budget]
wide funding; intelligent cars +
highways
spectrum: bill in committee now
want to take govt waves +
auction off to priv. sector.

* 800 ≈ undergrads
800 ≈ grad students
Small

* Rose Bowl stunts

Feinman
really famous CIT.
"Feinman Lectures on Physics"
Linnaeus Pauling
Milliken - founding Physicist;
Library named for him
Leroy Hood
pioneer in gen. engineering
(Human genome Project (?))

2001 COMPUTERS

LIVING INSIDE YOUR PC

In 1975 the world's first modern personal computer, the Altair 8800, came on the market. The machine was hopelessly primitive by today's standards. It arrived in pieces, to be assembled by the user. It had no keyboard and no display—hackers had to program it by flipping toggle switches on the front panel, and they read the results in binary form via flashing lights. It had 256 bytes of memory (today's garden-variety IBM PC clone has 640,000), no word processing or spreadsheets. *Popular Electronics* suggested that the Altair could be used to control a ham radio or a digital clock.

Considering how the personal computer has changed in the 13 years since then, it seems reasonable to assume that the device will be all but unrecognizable by the turn of the century, 13 years from now. Some experts talk of wristwatch-size computers that understand ordinary human speech, electronic books that contain entire libraries in digital form yet are the size of one slim volume of poetry. Others predict that the amount of information accessible through home computers—from telephone links and from disks with thousands of times the memory of present-day floppies—will be so formidable that we will use artificially intelligent electronic assistants to plow through it and find the material we really need.

The reason for such confidence is that there's no reason for the rapid progress in computer hardware to slow down anytime soon. Since the transistor was invented in 1947 and first commercialized around 1960, hordes of engineers have been refining it, learning to make smaller, more complex, and more efficient circuits out of silicon. Since 1975, personal-computing power—measured by the number of calculations per second—has increased by a factor of 10,000. But engineers are still far from exhausting silicon's inherent possibilities. Their exponential rate of progress is expected to continue until the theoretical limits of the material are reached, which will happen in the mid-1990s. By then each computer chip should be 1,000 times more powerful than it is now. The progress doesn't end with silicon, though. Engineers are also working with gallium arsenide, which operates even faster, and the Josephson junction, a transistor made of superconducting materials.

Meanwhile computer scientists are finding more efficient "architectures," or ways to arrange the basic elements of the computer. One technique is to make computers able to divide tasks into separate parts and take care of them simultaneously, instead of one after another. Another approach is to eliminate the barriers between processing (computing) chips and memory chips, barriers established at a time when processors were made of vacuum tubes and memory was made of little magnetic donuts. Since they are now both made of silicon, they can be moved physically closer together. That lets electronic signals travel shorter distances, which means faster computing. If any one of these ideas becomes commercially available by 2001, we can add another factor of 10 to the expected increase in computing power.

Data-storage capacities are keeping apace. Already, as much information can be stored on one optical compact disc as on 2,000 magnetic floppies or 130 books of 300 pages each. This makes it possible for computers to take on new, specialized purposes. Interactive video movies, where the user can play a role and influence the outcome of the story, are just one example.

But it's a lot easier to talk about computers' future quantitative power than it is to translate that power into the qualitative changes that will affect the ordinary person. Computer scientist Alan Kay, widely regarded as one of the true visionaries of personal computing, offers a way to think about it: "View a series of pictures at two frames a second," he says, "and then view them at twenty frames a second. In one case you have a series of still images, and in the other case you have animation." Something about the nervous system seems to respond to changes of that magnitude by drastically shifting the way it interprets the input. And that's just a factor of 10; a 10,000-fold increase in speed is *four* factors of 10.

Kay is an "Apple Fellow," a researcher working for Apple Computer on long-term projects chosen according to his own whim, as if he were an academic. In the early 1970s he was one of the computer scientists working on the Xerox Palo Alto Research Center project. Trying to imagine how computers could be designed so that anyone could use one, the Xerox team came up with some basic concepts so powerful they're now known to every computer user: the window, a way of looking into several documents or programs on a single screen; the menu, a list of options for what to do next; and the mouse, the tabletop device used for pointing on the screen. Having helped shape the first computer revolution, he's a good person to talk to about the next one.

One thing Kay predicts is that with all this power, instead of simply storing and retrieving data, we'll be able to mold that information into a working model of some aspect of the world and test ideas by varying the assumptions of the model. "For instance," he says, "most corporate executives, although they've never really thought about it, would much prefer to have a model of their company that they can actually pit against different situations," rather than rely on personnel records to see how changes in organization would affect the company's productivity.

This sort of simulation is already done on supercomputers; climatologists use models of the atmosphere to test the greenhouse effect, and engineers simulate airplane wings in wind to test aerodynamic designs without going to the trouble of building physical models. But since every user is interested in a different simulation, each has to create his own programming. Even if the personal computer at the turn of the century is as powerful as today's supercomputers, most of us won't be ready to do that.

It will be necessary to find a way to make such programming accessible to everyone. Kay is trying to do just that in his current project for Apple, the Vivarium, which he conjured up with Ann Marion, the project director. Tak-

ing a cue from the old Xerox days, Vivarium's staff tests its ideas with children, first through sixth graders at a Los Angeles school. The project is both an experiment in education and an attempt to create a new model for computer interaction.

When Vivarium's students study fish, they use a Macintosh computer to make pictures of fish and sea plants and then animate them. To make it a proper simulation, though, the computer fish have to act on their own, as real fish would. A group of graduate students at MIT has already done this—"the hard way," as Kay puts it—with conventional programming techniques and intellectual brute force. Now Kay and the MIT group are trying to discover the easy way—a way that the schoolchildren will be able to master. If that doesn't sound possible, consider that Kay has already taught ten-year-olds to write programs that do three-dimensional graphics. If the project is successful, it could provide the basis for a programming environment in which anyone can create almost any simulation he wants.

Another decisive shift Kay forecasts in the relation of user to computer is a "change from being on the outside of the computer to being on the inside." This will happen, he says, through the development of a "computer display you can put on your head." A screen will be mounted in a helmet, along with gadgets—already available—that can measure head movements with great accuracy. Thus, what appears on the screen will depend quite realistically on where you're looking, giving you the sensation that you're not just looking at a simulation—you're completely surrounded by it.

We'll be moving inside the computer in a more figurative sense as well: the computer will become part of our environment rather than a tool for a few specialized uses. We'll be surrounded by data sources. The number of sources of electronic information available by modem over phone lines is already enormous, and it will continue to grow. Soon these sources will carry sound and pictures as well as text, and they will gradually become available from a network of microwave transponders, much like the cellular phone network. Wherever we go, we'll have wireless access to a Niagara of data through a portable computer. "We're going to be living inside our computer network," predicts Kay.



Computer whiz Alan Kay predicts keyboards and bulky monitors are on the way out.

At the same time, he adds, "what we have to carry around with us to interact with the network is going to get smaller and smaller." Back in 1968 Kay proposed the concept of the Dynabook, or notebook-size computer. The Dynabook was intended as a sort of thought experiment, a spur to imagining what computers might become and how people might one day relate to them. But the Dynabook is now turning into a practical idea. Commonly used laptop computers are now as small as 6.5 pounds. Even smaller, if less practical, machines are available on the gadget frontier. This is the natural outgrowth of the continuing miniaturization of computer chips, combined with the liquid crystal technology being used in pocket TVs.

Now that the electronics have been shrunk and the screens flattened, the next challenge is to eliminate the keyboard, which is awkward both to carry around and to use. In the Toshiba 1000



laptop, for example, the keyboard is responsible for about 50 percent of the total surface bulk.

One way to get rid of the keyboard is to make the computer able to read handwriting. The user could write his input directly onto the screen using a stylus. This is just becoming possible today. Sensing the position of a stylus on the screen is not difficult, and computers can use artificial intelligence to identify letters. Systems that read printed type are already commonplace, and new ones that can deal with handwriting are appearing. These require that the letters be written separately and in a style known to the computer. They also require a fair amount of error correction by the user. But the accuracy of these machines will improve, and they will soon learn to deal with cursive writing.

And even a stylus pad takes up space. To overcome the bulk of a computer completely, you'd want to make it capable of recognizing ordinary speech. This has been the Holy Grail to hundreds of computer scientists for a long time. By 2001 increased computing power may bring it within reach. "When you have a thousandfold improvement, the results are just not predictable," says Raj Reddy, a longtime speech-recognition maven at Carnegie-Mellon University. Reddy believes that it may take 10 to 30 or more years to realize the ideal. Just how long depends on the answer to yet-unresolved theoretical questions and on the degree of commitment to the project. The basic elements of the problem have been identified, he says, and "they're all doable. The technology is all here. If someone started a crash effort today, it could become a fairly robust, useful technology in five years."

Present-day speech-recognition machines work fairly well with a limited vocabulary if they are limited to one person's voice; it's much easier to memorize one person's pronunciation than to understand the elusive sound patterns common to all speakers. These machines also usually require careful and separate enunciation of each word. This makes speech-recognition systems inconvenient at best. Hence they are used only for assembly-line control and other specialized purposes. "So long as you have a cooperative speaker who's highly motivated, you're fine," says Reddy.

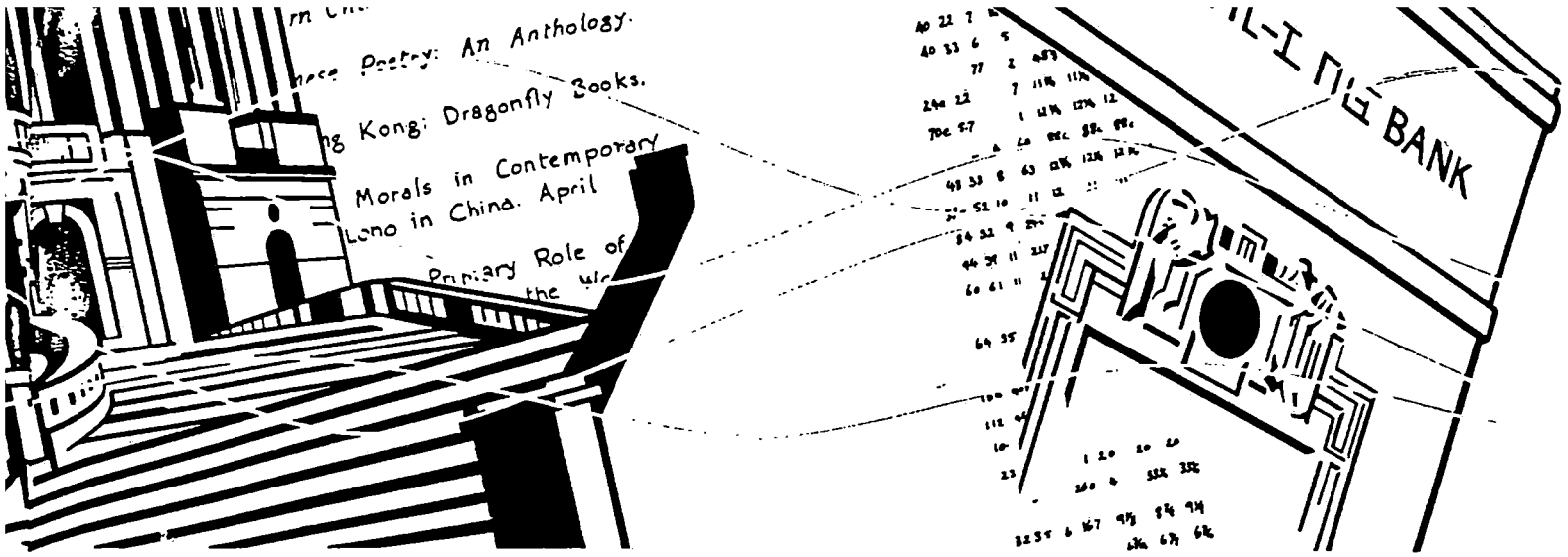
One of Reddy's graduate students, Kai-Fu Lee, has recently made a breakthrough in extending those limits. Lee's experimental program, SPHINX, can understand any speaker, without pauses between words; it works with a fairly complex, though specialized, subject matter (naval ship movements), and it has a vocabulary of 997 words.

SPHINX is based on the Hidden Markov method, a well-established technique for bridging the inevitable gap between the sound as actually heard and the sound as intended by the speaker. It does this by first determining all the sounds that might possibly have been intended and then picking the one most likely to form a word. Lee combined the Hidden Markov method with a system for guessing which word is most likely to appear in the context, and he reached 75 percent accuracy. Several more refinements upped that to 96 percent. Lee's method takes into account stress and intonation, and it always considers sounds in groups of three, rather than one at a time. Another improvement Lee is working on will give the program the ability to gradually adapt to a particular speaker's idiosyncrasies, just as people do. This hasn't paid off yet, but Lee considers it very promising.

None of this, however, is the same as making a computer continuously *understand* speech, and that will be necessary for truly conversational, spontaneous talk with a computer. As Alan Kay says, "In order for a computer to be humanlike, it will have to live in our world." And that will require artificial intelligence of a far more sophisticated sort.

Many computer scientists have come to the conclusion that most of intelligence is really wisdom, that is, the application of the correct bit of knowledge. Understanding speech is no exception. When we listen, we don't have to painstakingly identify each word because we already have a good idea what a person is talking about—we're applying what we already know about language and about the subject at hand. Computers will have to learn to do the

ILLUSTRATION BY ANN COLETTY PHOTOGRAPH BY TOYOJUMASTA PRESS



Pocket-size computers will give wireless access to information from hospitals, libraries, and banks.

same. The trouble is, that means providing them with a lot of background information—a "knowledge base" similar to our own.

Language comprehension is hardly the only aspect of artificial intelligence that's likely to be useful for ordinary people. True intelligence is certainly far in the future—further than 13 years. But artificial intelligence and personal computing will grow up together. Kay projects that one aspect of this development will be a gradual change from computers as tools that people manipulate to computers as assistants, or "agents," that people manage. Most of the work of computing will be done by the computer itself. A few very simple agents are here already, and more sophisticated ones will be around by 2001.

One example is NewsPeek, a system developed at MIT by Kay and by Walter Bender. NewsPeek edits a personalized newspaper just for you, every morning. It logs onto news-service data bases at night and looks for stories that match your interests. By noticing which articles you read carefully, it can keep up-to-date on what you like to read. Next it lays the stories out, sets headlines in sizes that reflect their importance to you, adds photos, and waits for you to read it.

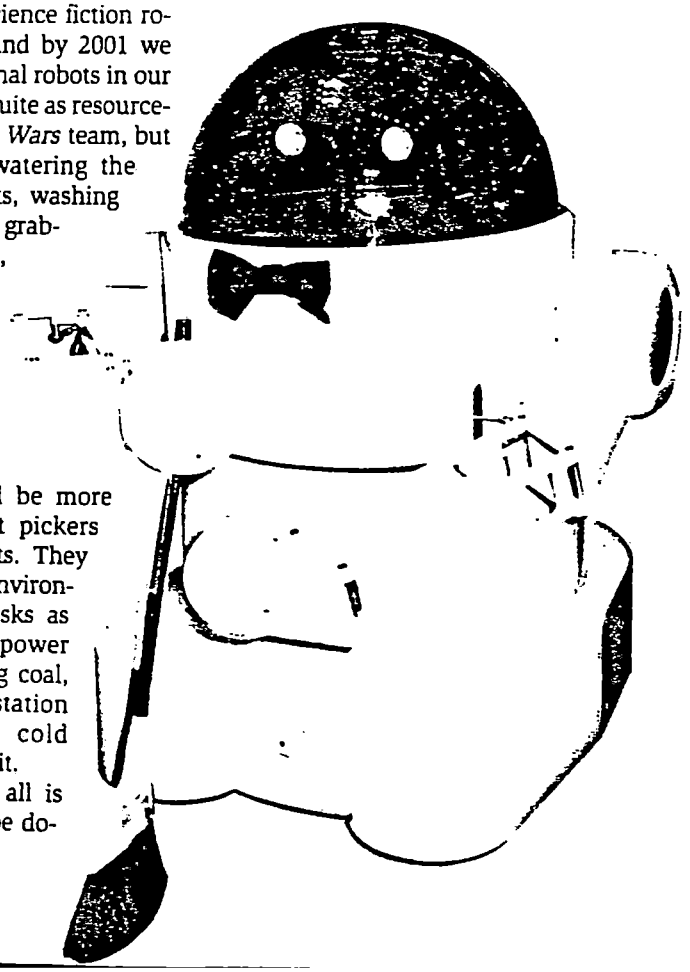
In fact, it's likely to know your interests better than you do. And since NewsPeek can also take messages for you, you might wake up to find that the banner headline, reflecting the most important story of the day, reads something like HAPPY BIRTHDAY. Now *that's* a personal computer. —*Tom Waters*

THE ROBOT REALITY

Although we might wish otherwise, robots like the anthropomorphic, butlerlike C-3PO and his garbage-can-size, hemisphere-headed buddy, R2-D2, are still pure fantasy. Robots exist, but they're mostly giant mechanical arms that do a few narrow tasks, not talking, thinking, independent entities.

In the automobile industry, for example, robot arms staff entire assembly lines. Some have electrode "fingers" that weld parts together. Others are programmed to spray-paint cars more thoroughly and evenly than a human could. Still others are material handlers that pick up parts and place them on assembly lines or load and unload pallets. In its large-appliance division in Louisville, Kentucky, General Electric has optic-sensor-equipped robots that "see" refrigerator compressors, pick them up, and move them from one conveyor to another. And then there are the robot explorers: last summer the French Institute for the Research and Exploitation of the Sea used a robotic-armed submarine to snatch treasures from the sunken RMS *Titanic*.

But the age of the science fiction robot is getting closer, and by 2001 we may finally have personal robots in our homes; they won't be quite as resourceful or clever as the *Star Wars* team, but they may be up to watering the plants, feeding the pets, washing the car—maybe even grabbing us a beer, chips, and some guacamole from the refrigerator.



More significant, however, will be the robot's expanded use for mundane commercial and service jobs. Robots will be more commonplace as fruit pickers and hospital attendants. They will be used for such environmentally dangerous tasks as cleaning up nuclear power plant accidents, mining coal, and repairing space-station components in the cold airlessness of Earth orbit.

Most impressive of all is that some robots will be do-

"I see a more direct realization of the R2-D2 concept of robotics."

ing these jobs autonomously. Nearly all today's robots have to rely on either direct or preprogrammed instructions from humans. The 1979 Three Mile Island disaster, for example, is still being cleaned up by a six-wheeled, one-armed robot named Rover, but Rover is controlled at all times by human operators. A robotic arm at Memorial Medical Center in Long Beach, California, can precisely locate a tumor in a patient's brain—but it has to be programmed with the tumor's coordinates, based on a brain scan, in advance.

An autonomous robot, by contrast, will be able to evaluate situations as it encounters them and react accordingly. It's a convenient capability for a nuclear plant cleaner or a coal miner. But it's absolutely essential for a robot operating beyond the reach of human controllers—on Mars, say, or in the deepest parts of the sea.

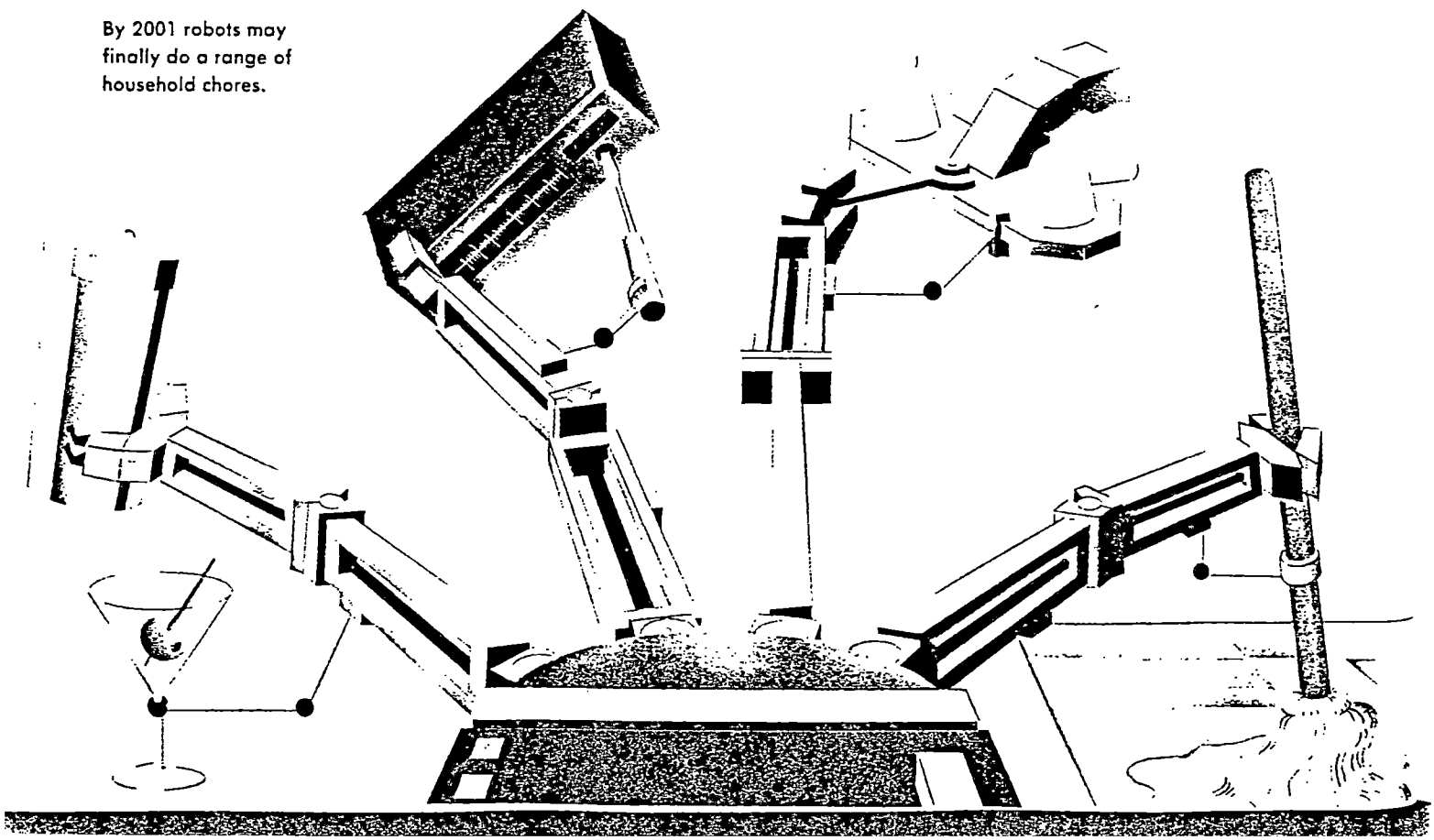
Researchers have been working on robot autonomy for decades. In 1969 SRI International developed a bulky robot, appropriately named Shakey, programmed to maneuver itself around a controlled environment. It had a television camera, huge onboard logic and camera-control systems, a bump detector (which looked like the rubber sides of an amusement-park bumper car), and wheels. The project was a crude attempt to create a robot that could move from room to room without charging into the children or the china cabinet.

Shakey was far too primitive for actual consumer use. But its designers were already anticipating one of the two major lines of inquiry pursued today: the development of true artificial intelligence—robotic brains able to reason, make decisions, and learn—and sophisticated dexterity, so that robots can manipulate their environment.

At the forefront of robotics research is Michael Kuperstein of Neurogen Corporation in Brookline, Massachusetts. He has developed an integrated robotic system: two cameras that act as eyes and an industrial, jointed arm with a clincher hand. He has also incorporated the supercomputing power of an image processor.

Kuperstein programmed the image processor to simulate the functioning of a neural network, which is composed of a set of identical processing elements that work together to recognize patterns. It is an attempt to model the way neurons interact in the brain. Information is represented in a neural network by the strengths of the connection between the processors. The more useful the information, the stronger the connection becomes; useless or incorrect information leads to weaker connections. Other contemporary robots still operate by more conventional programmed approaches to artificial intelligence. But Kuperstein's robot—called INFANT (Interacting Networks Forming Adaptive Neural Topographies)—is told what to do in a certain environment and through trial and error learns to do it.

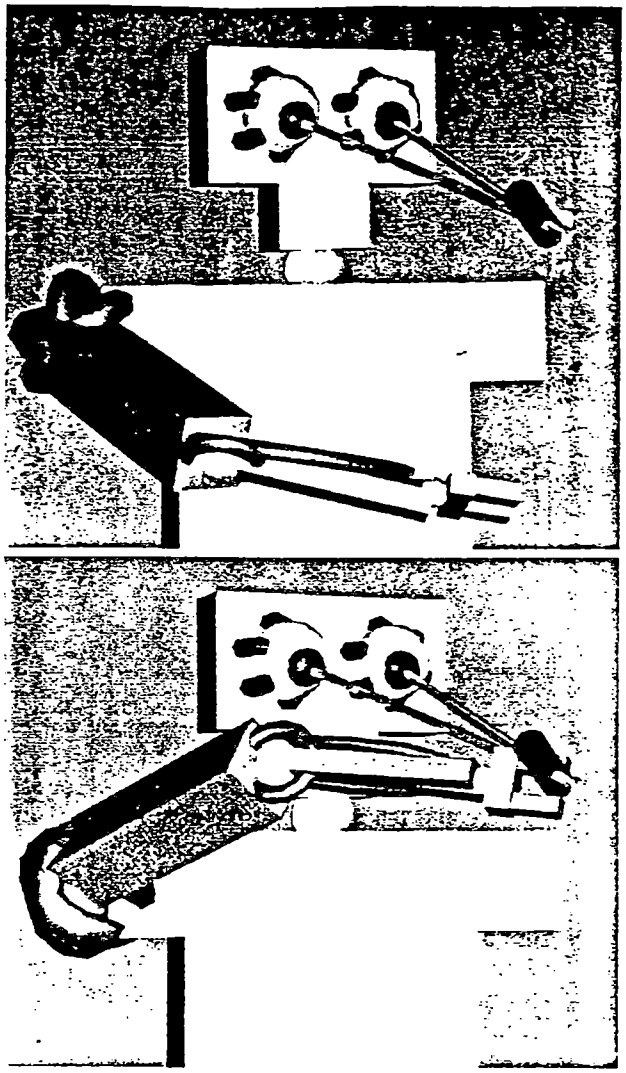
In the first phase of the learning process Kuperstein gives the robot objects to hold; a ball, for example. "The machine explores its space by moving its arm randomly and forming images of its arm and the ball," he says. "At each position the system takes a view of the arm and of the ball, and the images are transformed into a neural representation." That phase lasts about two hours. In the second phase Kuperstein places the ball arbitrarily in the robot's environment and instructs the ro-



By 2001 robots may finally do a range of household chores.

bot to pick it up. INFANT can't yet do that on its first try, though it comes close. In the third phase the robot observes its attempts to grab the ball and learns by remembering those positions that bring it closer to the ball and ruling out those that don't.

"In the final phase, after failing to grasp the object several times," says Kuperstein, "it uses what it's learned to adjust itself until it gets a completely accurate performance." In other words, it picks up the ball. During phase one the trial-and-error cycle is repeated 2,000 to 4,000 times; that is, as many as 4,000 different postures are calculated and compared. Phase three takes another ten cycles or so. Over the course of these associations the difference between the computed arm position and the actual arm position gets smaller and smaller; thus, the computer learns by comparison. This may seem long and tedious for just one simple task, but it's a major step in connecting neurobiology to robotics.



Michael Kuperstein's robot, INFANT, has developed the ability to learn through old-fashioned trial and error.

It is quite similar to the way a baby learns to grasp objects. Think about a human infant in her crib. She has eyes that see her arms and fingers move, and she begins to realize her control over them. She moves an arm and grasps a stuffed animal and realizes she can pull it toward her. Then she grasps a railing and realizes she can't pull that toward her. She's learned the difference between two objects in her environment, and her behavior has been modified. This is how Kuperstein's image processor, cameras, and arms work. He began his project using the Swiss psychologist Jean Piaget's concept of circular reaction in human learning: that a child explores the world through movements, perceives the consequences, and then makes an association.

All the intelligence in the world won't make much difference, however, if a robot can't manipulate its environment based on what it's learned. Stephen Jacobsen of the University of Utah is one of those trying hard to improve robot dexterity; he predicts that robotic limbs will certainly have gotten far more adroit and sensitive by 2001, but he's cautious about forecasting huge leaps in either dexterity or artificial intelligence within just 13 years.

"New computing comes along daily, so machine complexity will be chipped away considerably in ten to fifteen years," Jacobsen says. "But you have to realize, a hand is an enormously complex thing in itself, with ten times the amount of actuators that even a car has.

"I just don't think we know enough yet to make machines that can function in environments in which they don't already know what's going to happen. And I think it would be stretching it a bit to say this will be possible ten years from now."

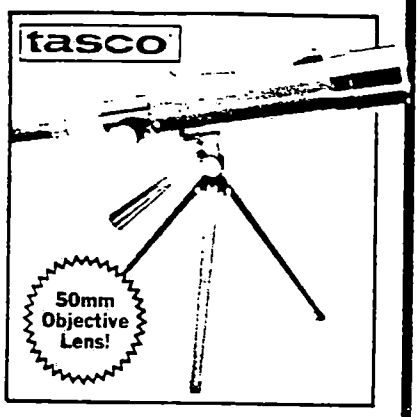
Walt Weisel, president of Prab Command, a Kalamazoo, Michigan, robotics company that has created a division devoted exclusively to healthcare robotics, is far less cautious. His company recently introduced a voice-activated computer and robot designed specifically for the handicapped, and he is convinced that improvements in robotic technology will be rapid.

"This system can give handicapped people complete access to all telephone services, connection with remote data banks anywhere in the world. That opens up a brand new world for them: they can now enter businesses such as computer programming, accounting, engineering, architecture and other design operations, publishing—the list goes on." The robot half of the device, controlled by voice through the computer half, is a mechanical arm with a two-fingered hand that can insert and remove floppy disks and even hand the user a glass of soda or an orange. The arm is crude, however; it can't peel the orange.

But, says Weisel, "that's just a matter of gathering all our technologies and integrating them. It's a matter of getting specific people working on mobility, vision, sensing; and others developing and perfecting dexterous arms and fingers." Sounds simple enough, but remember that it still takes Kuperstein's INFANT hours just to figure out how to pick up an object. It also took years of research to create computer systems powerful enough and programs accurate enough to guide industrial robots with enough savvy to pick up one car part, weld it to another part, and move the finished piece on down the line.

Still, Weisel predicts remarkable progress over the next 13 years. "What I see is a more direct realization of the R2-D2 concept of robotics," he says. "I feel we'll have commercially packaged systems that can walk or roll, with onboard telemetry to send information to the robot's 'master'—wherever he or she may be. Think about it. With a cellular telephone and a computer you

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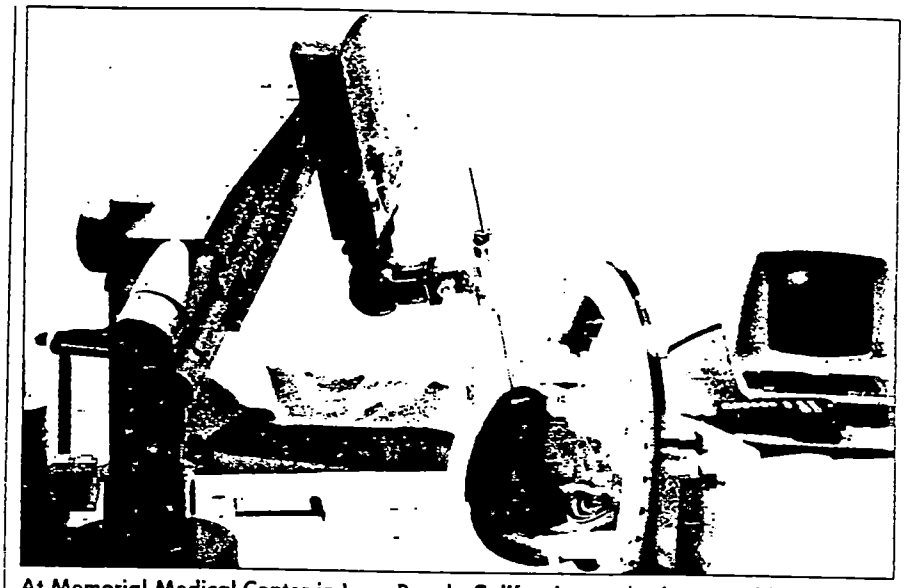
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At Memorial Medical Center in Long Beach, California, a robotic arm guides the surgeon to a brain tumor's precise location, within .002 inch.

will call up your home robot from anywhere and tell it to water the plants or wash the car." Joe Engelberger, chairman of Transitions Research Corporation and sometimes called the father of industrial robots, also firmly believes home systems will be a staple by the turn of the century: "We did a survey, and the number one thing that women want is a robot that will clean their bathrooms."

To do so, a robot will need not just intelligence and dexterity, but a way of connecting the two. That's the specialty of Andras Pellionisz, a biophysicist at New York University Medical Center. Pellionisz is best known for his studies of the cerebellum, that part of the brain that coordinates limb movements. He has devised a theory of how the cerebellum integrates two distinct coordinate systems—that of the sensing organs and that of the muscles—to perform such complex tasks as grasping and walking. And there is no reason the theory can't be adapted to robots.

In his cluttered university office Pellionisz demonstrates just how convincing his ideas are. He points to the screen of a Macintosh computer on which he has created an image of a cat's leg. The leg is animated according to his theories of movement—and indeed, its movement on the screen looks remarkably lifelike. Pellionisz issues a command to the Mac, and the leg speeds up and slows down realistically. Then he points to a graph at the side of the picture that shows the movement of each muscle and joint in the limb. "This," he says, "is just a first step in understanding the relationship between intelligent systems and graceful movements.

"But limbs are really extraordinarily primitive systems," Pellionisz adds. "By the year 2001, they'll be mere toys. The difference between systems of today and systems of tomorrow will not be their strength or their human qualities—it will be their intelligence. The real goal is not just robotic arms that can do something, but robotic systems that can recognize a situation, make a decision, and *then* do something."

Just how much machines like Kuperstein's INFANT will be able to do in the near future depends a lot on how fast they can mature into responsible adult robots. By 2001, Kuperstein predicts, INFANT and its contemporaries may have reached adolescence. Perhaps they will have learned enough to perform simple housecleaning tasks, or even pick oranges off trees. But to do more than that may take some teenage rebellion.

"The more flexible and skilled you want robots to become," says Kuperstein, "the more independent from their human designers they have to become. It's difficult to constrain the kinds of mistakes these things are going to make. You want your child to learn from its mistakes; well, these machines have to make their own mistakes and learn from their own experiences."

—Mark Kemp

U.S. TECHNOLOGY POLICY



EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C.

SEPTEMBER 26, 1990

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

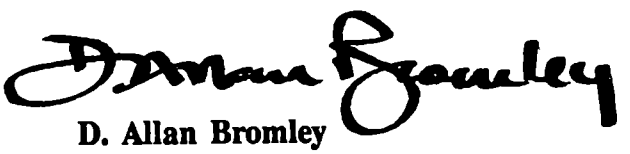
September 26, 1990

Dear Messrs. Chairmen:

I am pleased to transmit to you a statement of the Administration's technology policy. This paper brings together the many facets of technology policy, describes what they are, and shows how they fit into a comprehensive framework. It consists of the goal and strategy of this policy and the program implementation proposed in the Administration's Fiscal Year 1991 budget submittal to Congress. It is also intended to serve as a baseline for future dialogue and discussion of technology issues, both inside and outside of the government. Areas associated with classified national security technologies are not included.

The issues involved in technology policy are varied and complex. Nonetheless, the underlying theme is that all sectors of our society have important roles to play in achieving the goal of this policy. There are formidable challenges facing us, but by working together and capitalizing on our strengths, we can ensure continued U.S. economic and industrial competitiveness.

Sincerely,



D. Allan Bromley
Director

The Honorable Robert C. Byrd
Chairman
Appropriations Committee
U.S. Senate
Washington, DC 20510

The Honorable Jamie L. Whitten
Chairman
Appropriations Committee
U.S. House of Representatives
Washington, DC 20515

U.S.
TECHNOLOGY POLICY



EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C.

SEPTEMBER 26, 1990

U.S. TECHNOLOGY POLICY

A nation's technology policy is based on the broad principles that govern the allocation of its technological resources. Competitive market forces determine, for the most part, an optimal allocation of U.S. technological resources. Government can nonetheless play an important role by supplementing and complementing those forces. Technology policy is not something that, once set in place, remains immutable. Broad principles exist, but effective technology policy requires sufficient flexibility to permit response to changing national and international situations. We are in an era marked by increased international economic interdependency and increasingly stronger technological capabilities in other industrial nations. These factors pose competitive challenges for U.S. firms as well as opportunities. In formulating a national technology policy, consideration must be given to a nation's traditions, its strengths and weaknesses, and the international environment in which it exists.

In almost all respects the U.S. science and technology base remains the world's strongest. The Nation's research universities and the ability of its people to innovate remain the envy of the world. Nonetheless, industrial competitiveness depends on many factors besides technology. Our strengths in technology and innovation have not prevented an erosion in market shares of U.S. companies in many industries. As new products mature, the advantage quickly shifts from the innovator to the efficient producer. We have also seen the importance of high rates of capital investment for the industrial competitiveness of Japan, Europe, and the Pacific Rim countries.

The competitive challenges American firms face are multifaceted and complex. There will be no facile, short-term solutions. We, in this Administration, believe it is essential that we recognize and use the strengths of our economic system more effectively to help U.S. firms remain competitive. In order to do so, all elements of our society must recognize that while we possess many strengths and assets, problems do exist, and that we can mobilize our resources and solve them. At the same time, we need to refrain from actions that might distort our basic system of free enterprise -- the Nation's ultimate strength.

In order to build on its strengths, U.S. society needs to focus on ensuring:

- a quality workforce that is educated, trained, and flexible in adapting to technological and competitive change;
- a financial environment that is conducive to longer-term investment in technology;
- the translation of technology into timely, cost competitive, high quality manufactured products;
- an efficient technological infrastructure, especially in the transfer of information; and

- o a legal and regulatory environment that provides stability for innovation and does not contain unnecessary barriers to private investments in R&D and domestic production.

In addition, the Federal Government, industry, and academia need to take advantage of opportunities for:

- o technology transfer and research cooperation, particularly involving small and mid-sized companies;
- o building upon state and regional technology initiatives; and
- o mutually beneficial international cooperation in science and technology.

With its proven human resources and successful tradition of manufacturing, U.S. industry can assert the leadership required to meet the competitive challenges and to capitalize on its opportunities. The principal role of the Federal Government will be to provide an environment conducive to long-term economic vitality, and not allow special interests to divert attention or resources from this goal.

The following sections provide more detail on the Administration's goals and strategy to implement its technology policy, and then highlight some of the steps that it has already taken to improve the economic and technological competitiveness of U.S. industry.

Goal of Technology Policy

The goal of U.S. technology policy is to make the best use of technology in achieving the national goals of improved quality of life for all Americans, continued economic growth, and national security.

Strategy to Implement U. S. Technology Policy

The goal of U.S. technology policy is to be achieved by maintaining a strong science and technology base, a healthy economic environment conducive to innovation and diffusion of new technologies, and by developing mutually beneficial international science and technology relationships. Implementation of the policy must recognize that all parts of the economy -- the Federal Government, state and local governments, industry, and academia -- have roles to play. The education system provides the essential flow of well-trained, innovative manpower. Researchers in academia, the

Federal laboratories, and industry all contribute to the science and technology base. Industry makes the investments necessary to turn this knowledge base into commercial products and processes. Federal, state, and local governments support research both directly when they fund specific R&D projects, and indirectly through tax and other incentives for private sector R&D investment. The Federal Government also sets the overall macroeconomic and legal environment in which industry's decisions about product and process development and commercialization take place.

In that context, the Administration's strategy to implement U.S. technology policy includes the following major elements:

Role of the Private Sector

While the government plays a critical role in establishing an economic environment to encourage innovation, the private sector has the principal role in identifying and utilizing technologies for commercial products and processes. In particular, the private sector has the responsibility to:

- conduct research and development to advance industry-related knowledge and technology;
- identify and aggressively pursue potential commercial applications for technologies developed by its own laboratories as well as by universities, Federal laboratories, and foreign sources;
- increase quality, output, and productivity by undertaking necessary investments in physical capital;
- improve the skills and abilities of its workforce to meet its specific needs; and
- participate cooperatively in improving the quality of U.S. education.

Government policies can help establish a favorable environment for private industry to conduct these activities but cannot substitute for aggressive private sector action.

Government Incentives for the Private Sector

o Create an environment conducive to technological competitiveness by ensuring that technology policy concerns are factored into the formulation of related policies (e.g. fiscal, monetary, trade, environmental, etc.) with the overall objective of enhancing U.S. economic growth.

o Encourage private technology-related investment through Federal monetary and fiscal policies. For example, reducing the capital gains tax differential and making permanent as well as enhancing the tax credit for research and experimentation will provide incentives for added investment. Incentives can also be provided through appropriate tax policies.

- Provide an appropriate legal environment at the Federal level that removes unnecessary obstacles to innovation. Reducing the uncertainties about antitrust enforcement related to inter-firm cooperation in research and technology development encourages the pooling of limited resources and a rapid diffusion of results while still protecting against anticompetitive practices. Reducing the antitrust uncertainties about joint production ventures will also enable firms to cooperate in the development and introduction of new products.

- Revise Federal procurement regulations and practices to permit greater integration of government and commercial production at the factory level, as well as encourage greater innovation and efficiency in development and production. Also encourage the use of commercial products, to the extent feasible, for defense, space, and other government applications.

- Improve opportunities for companies to commercialize technologies and computer software developed during the performance of government contracts by allowing the contractors to retain rights in technical data and by protecting their trade secrets.

- Provide a stable regulatory environment in order to decrease risk for private investment.

- Seek greater harmonization of regulations and standards for products and processes with our major trading partners.

- Encourage increased U.S. participation in multi-lateral international standardization efforts through the standards activities of the National Institute of Standards and Technology.

- Seek better international protection of intellectual property to allow more benefits to be recovered from R&D investments.

Education and Training

- Revitalize education at all levels including not only the training of scientists, engineers, and the technical workforce, but also educating our population to be sufficiently literate in science and technology to deal with the social issues arising from rapid scientific and technical change. Achieving such a goal will require a broad-based approach involving business, academia, and educational organizations, as well as Federal, state, and local governments.

- Develop a framework for Federal interagency coordination and collaboration in mathematics, science, engineering, and technology education. The goal is to define an effective and appropriate role for the Federal government in support of the states, localities, and universities as they improve science and technology education to build human capital in the U.S.

- Encourage continuing education and training, recognizing that, particularly in scientific and technological fields, education must be a lifelong activity.

Federal R&D Responsibilities

- Increase Federal investment in support of basic research. Private industry does not invest heavily in basic research because the payoffs are so unpredictable and diffuse that individual firms cannot be confident of fully recovering their investments. However, the long-term potential benefits of this research are so large that society cannot afford not to make the investment, especially in university research which, in addition to new knowledge, also produces trained scientists and engineers of the future.

- Participate with the private sector in precompetitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications. In many cases these technologies have evolved from government-funded basic research, but technical uncertainties are not sufficiently reduced to permit assessment of full commercial potential. In pre-competitive research, which occurs prior to the development of application-specific commercial prototypes, research results can be shared among potential competitors without reducing the financial incentives for individual firms to develop and market commercial products and processes based upon the results.

- Continue the Federal government's development of products and processes for which it is the sole or major consumer, such as national defense, provided that no commercially available products can be substituted. The government, in such cases, must rely principally on the private sector to undertake the development process. Revise current Federal procurement regulations to strengthen the abilities of companies involved in developing and demonstrating these products to use the same research results and technologies for commercial purposes.

- Maintain a strong Defense technology base to provide options for future weapons systems development and to help avoid technological surprises by potential adversaries. Special emphasis needs to be placed on shortening the time required for transferring R&D results to production and on using commercial products.

- Streamline Federal decision-making structures and mechanisms to eliminate unnecessary and cumbersome regulations and practices that inhibit industrial competitiveness.

- Encourage international cooperation in science and technology, where mutually beneficial, and inform U.S. researchers of opportunities to participate in R&D initiatives outside the U.S.

Transfer of Federally Funded Technology

- Improve the transfer of Federal laboratories' R&D results to the private sector. Where appropriate, these laboratories should give greater consideration to potential commercial applications in the planning and conduct of R&D, and these efforts should be guided by input from potential users. To achieve this goal, there must be a closer working relationship among these laboratories, industry, and universities. Defense-related laboratories can make major contributions while still providing adequate safeguards for classified information.

- Promote increased industry-Federal laboratory-university collaboration, including personnel exchanges, to help convert Federally-supported R&D into new technologies that the private sector can then turn into commercial products and processes.

- Promote and encourage access by U.S. industry to Federal laboratories within the guidelines established by the Federal Technology Transfer Act of 1986 (P.L. 99-502), other existing legislation, and Executive Order 12591.

- Expedite the diffusion of the results of Federally-conducted R&D to industry, including licensing of inventions and removal of barriers to commercialization of Federally developed computer software.

- Encourage direct laboratory-industry interaction within broad, flexible Federal guidelines, since effective technology transfer occurs at the operational level.

Federal-State Activities

Recognize the importance of decentralization, and encourage states to develop programs that take into account the individual characteristics of each state. Federal programs in such areas as education, training, the national infrastructure, and regional generic technology centers, should build upon state initiatives.

Programs To Implement U.S. Technology Policy

The Administration has undertaken a broad range of programs and initiatives aimed at translating the technology policy into action. These programs and their associated budget levels requested for Fiscal Year 1991, where applicable, are summarized here.

Incentives for the Private Sector

The Administration has proposed improvements in incentives for private sector innovation by:

- o Reducing the tax rate on capital gains permanently to spur entrepreneurial activity.

  The Administration has proposed restoring a capital gains tax differential such as existed before the Tax Reform Act of 1986. A lower tax rate on capital gains will encourage investors and entrepreneurs to make the investments necessary to be competitive.

- o Making the research and experimentation (R&E) tax credit permanent to reduce uncertainty.

  Under current law, the R&E tax credit is scheduled to expire on December 31, 1990. The Administration proposal to make the credit permanent would permit businesses to establish and expand research facilities without fearing that the tax laws will suddenly change.

- o Protecting intellectual property through international negotiations.

  The Administration is aggressively pursuing improved international protection of intellectual property. The current negotiations in the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) are an important forum for developing better international rules. Negotiations on intellectual property rights are also being conducted in the World Intellectual Property Organization and in trilateral talks with the European Community and Japan. In addition, the U.S. is pursuing bilateral negotiations on intellectual property rights under the provisions of the 1988 Omnibus Trade and Competitiveness Act.

- o Liberalizing export controls to enhance high technology product exports.

  Dramatic changes in the Eastern European security environment have permitted an Administration re-evaluation of U.S. export controls, and paved the way for an expanded trade potential for U.S. high technology industries.

- o Reforming product liability laws to restore balance to the tort system.

  The Administration supports the adoption of uniform product liability standards across the 50 states based on three principles of fairness: the right of an innocent person to fair compensation for actual damages; liability based on responsibility for harm and not ability to pay; and encouragement of alternatives to costly litigation. The proposed changes to product liability laws would

maintain incentives to produce safe products, but would restore balance to the tort system and reduce uncertainty -- particularly for new products.

o Reforming the Federal procurement process.

The Administration supports continued efforts to streamline the procurement process, reduce its complexity and paperwork burden, and provide contractors with incentives to innovate and reduce costs. The Administration has proposed changes in legislation and regulations to foster commercial style competitive procedures for the acquisition of commercial products. A revision of the Federal Acquisition Regulations is being drafted that will allow contractors to retain commercial rights in technical data developed under Federal contracts. The Administration is also developing a policy mandating increased agency use of performance based contracting that gives contractors more freedom and incentive to innovate.

o Removing barriers to research, innovation, and development.

The Administration supports continued elimination of unwarranted regulation. Deregulation can spur innovation as well as lower prices. It also requires a continuous reexamination of existing regulatory policies to avoid unnecessary stifling of new products and processes. The Administration has proposed antitrust legislation that would reduce the legal uncertainties for companies to enter joint production ventures while still protecting against anticompetitive practices. Challengers would be required to prove that such ventures would harm competition. The legislation would also eliminate punitive treble-damage awards under certain circumstances.

Education and Training

In addition to the President's broad initiatives on education, there are a number of programs directed at improving education in mathematics and science and at training of the technical workforce. These include:

o National Science Foundation: $463 million plus research assistantships proposed in Fiscal Year 1991

The National Science Foundation has a broad range of programs dealing with mathematics and science education and human resources at all levels. Major programs are:

- Research career development (graduate research fellowships and enrichment activities for talented high school students).

- Teaching materials development and informal science education (aimed primarily at the pre-college level).

- Teacher preparation and enhancement (upgrading quality of faculty, providing Presidential Awards for Excellence in Science and Mathematics Teaching, and developing model programs for women, minorities, and the handicapped).

- Undergraduate science, engineering, and mathematics education (includes instrumentation grants, curriculum development, faculty revitalization, comprehensive regional centers for minorities, and research experiences for undergraduates).

In addition, almost 16,000 graduate students are supported by research assistantships through regular research grants to universities.

o Department of Education: $333 million proposed in Fiscal Year 1991

- Eisenhower mathematics and science program (provides funds to help State and local educational agencies carry out programs to train teachers and improve instruction in mathematics and science).

- Adult education program (aimed at skills needed to cope with new technologies and providing for workplace literacy).

o National Institutes of Health: $292 million plus research assistantships proposed in Fiscal Year 1991

- Almost 12,000 graduate students receive training grants.

- Tens of thousands of graduate students are supported by research assistantships through the $4.4 billion in extramural research grants.

o National Aeronautics and Space Administration: $51 million proposed in Fiscal Year 1991

Program activities cover informal K-12 science education, mobile presentations on space to elementary and secondary schools, teacher workshops and internships at NASA research centers, grants for undergraduate and graduate students, and programs for minorities in science and engineering education.

o Department of Energy: $25 million plus research assistantships proposed in Fiscal Year 1991

- Programs include science and mathematics exposure for middle and high school students, research training of undergraduates, and graduate fellowships in science and engineering.

- An estimated 4,000-4,500 graduate students are supported by research assistantships through research grants to universities.

o Department of Defense: $364 million projected for Fiscal Year 1991 for non-military personnel

- Pre-college programs (summer programs for minorities).
- Undergraduate programs (primarily ROTC scholarships in technical fields).
- Graduate fellowships and research assistantships.
- Post-doctoral and faculty research appointments.

o Department of Agriculture: $125 million proposed in Fiscal Year 1991

- Challenge grants to strengthen undergraduate education.
- Capacity building grants to strengthen teaching and research programs in the "1890 Land Grant" institutions.
- National needs fellowships to recruit and train scientists in the most critically deficient areas.
- Graduate assistantships associated with research grants projects. About 13,000 graduate students are supported for graduate studies.
- Ag-In-The-Classroom to support science strengthening in K-12 programs.
- Research apprenticeships to bring high school students into university and government laboratories to stimulate interest in science.
- School enrichment program to function as a catalyst between schools and community to strengthen science programs.
- Postdoctoral program in Agricultural Research Service and Animal and Plant Health Inspection Service laboratories.

Federal R&D Responsibilities

The Fiscal Year 1991 budget proposes to allocate about $71 billion for research and development. This is an increase of $4.5 billion, or 7 percent, over 1990 enacted levels. Civilian R&D will increase by 12 percent, while defense-related R&D will increase by 4 percent. Within this total, $12 billion will be allocated for basic research, an increase of $1 billion or about 8 percent over 1990. The budget contains a number of new and expanded programs that will contribute to the Nation's R&D enterprise and competitive posture. These include:

- o A 13 percent increase in the National Science Foundation's budget request for research and facilities, which account for over 75 percent of the NSF budget. Support for basic science and engineering is the foundation on which U.S. technology is built. Within the overall increases there are emphases on Science and Technology Centers, networking and communications, Engineering Research Centers, and major research equipment for universities.

- o Developing advanced technologies to meet Defense and civilian agency needs. Based on the results of a special survey of the support for selected advanced technologies that are funded by more than one Federal agency, the budget proposals are:

  - Robotics - The budget provides $192 million to six Federal agencies for support of robotics R&D. The focus of this R&D is on the development of systems that are more autonomous and capable of interacting with changing and uncertain environments.

  - High Performance Computing - The budget provides $469 million for Federal support of R&D focused on high performance computing. This activity includes the full range of advanced computing technologies as well as systems and applications software, networking, and underlying research and human resource infrastructure.

  - Semiconductors - The budget provides $537 million for research on semiconductor materials, development and application of semiconductor materials to meet agency mission needs, and support of R&D on semiconductor manufacturing processes. The largest single Federal program is DOD funding of $100 million per year for SEMATECH, a semiconductor industry R&D consortium.

  - Superconductivity - The budget provides $215 million for superconductivity R&D. Programs in five Federal agencies deal with both high temperature and low temperature superconducting phenomena and materials.

  - Advanced Imaging Technologies - The budget provides $118 million for advanced imaging R&D. Advanced imaging systems include interactive graphics, high definition displays, advanced signal processing, and advanced digital switching technologies.

- o Improving productivity and the quality of life through biotechnology. The budget proposes $3.6 billion for biotechnology R&D. In pharmaceuticals, foods, agriculture, waste management, and energy, biotechnical advances offer the possibility of improvements that will make a real difference in people's lives.

- o Developing technologies for improved transportation. The budget proposes funding for transportation R&D of $1,527 million. This R&D is aimed at maintaining a modern, efficient transportation infrastructure, an essential factor

in being industrially competitive. Federal programs are focused on aeronautics, highways, mass transit, railroads, maritime, water, aviation, and other transportation areas.

- o Promoting alternate sources of energy. For conduct of energy R&D programs in the Department of Energy, the budget proposes total funding of $2,450 million. The R&D is aimed at maintaining abundant, reliable, and economic sources of energy. Federal programs cover a broad spectrum of energy technologies including solar, renewable, conservation, nuclear fission, nuclear fusion, and fossil energy, and supporting energy sciences.

- o Enhancing industrial productivity and development of standards. The budget proposes $198 million for the National Institute of Standards and Technology. R&D in fundamental measurements and standards provides the foundation for U.S. industry, commerce, and science to achieve levels of accuracy and compatibility required to support technological development, efficient processing, process control, and quality assurance. Special activities include R&D on advanced manufacturing technologies. In addition, the Advanced Technology Program provides grants to industry-led ventures to support research on pre-competitive generic technologies.

Transfer of Federally Funded Technology

Many important steps have been taken, pursuant to the Federal Technology Transfer Act and other legislation, to increase the degree to which Federal laboratories collaborate with private industry in commercializing the results of Federally-funded research and development. These activities include:

- o Establishment of over 200 active cooperative research and development agreements between Federal laboratories and private companies.

- o Creation of the Precision Manufacturing Technology Program by the Department of Energy to provide U.S. industry greater access to the extensive manufacturing technology, expertise, and facilities available within the Department's Defense Programs weapons complex.

- o Formation of the Biotechnology Research and Development Consortium, a joint research effort between the Department of Agriculture's Northern Regional Research Center, the University of Illinois, the State of Illinois, and six U.S. companies.

- o Formation of a joint venture in high temperature superconducting materials and applications by Du Pont, Hewlett-Packard, and Los Alamos National Laboratory.

- o Establishment of Regional Manufacturing Technology Centers. The budget provides $5 million for this program. The approach is to reduce the barriers

faced by small- and medium-sized manufacturers in adopting new technology by creating awareness and providing up-to-date, practical information and expertise on manufacturing technologies and practices.

Federal-State Activities

Federal programs have already been initiated to build upon the advantages offered by decentralized programs operating at the state and local level. These programs include:

- Department of Commerce Clearinghouse for State and Local Initiatives on Productivity, Technology and Innovation:

  The Clearinghouse gathers and analyzes information on the many technology development centers at the state and local level. It will help to develop a network of contacts among state and local officials and staff.

- Small Business Development Centers:

  Each Small Business Development Center (SBDC) serves as a one-stop assistance center for businesses and provides services ranging from pre-business start-up counseling to technical advice for existing businesses. The centers have a legislative mandate to assist in technology transfer, make use of Federal laboratories and equipment, and coordinate and conduct research they deem worthwhile.

- University Centers Program:

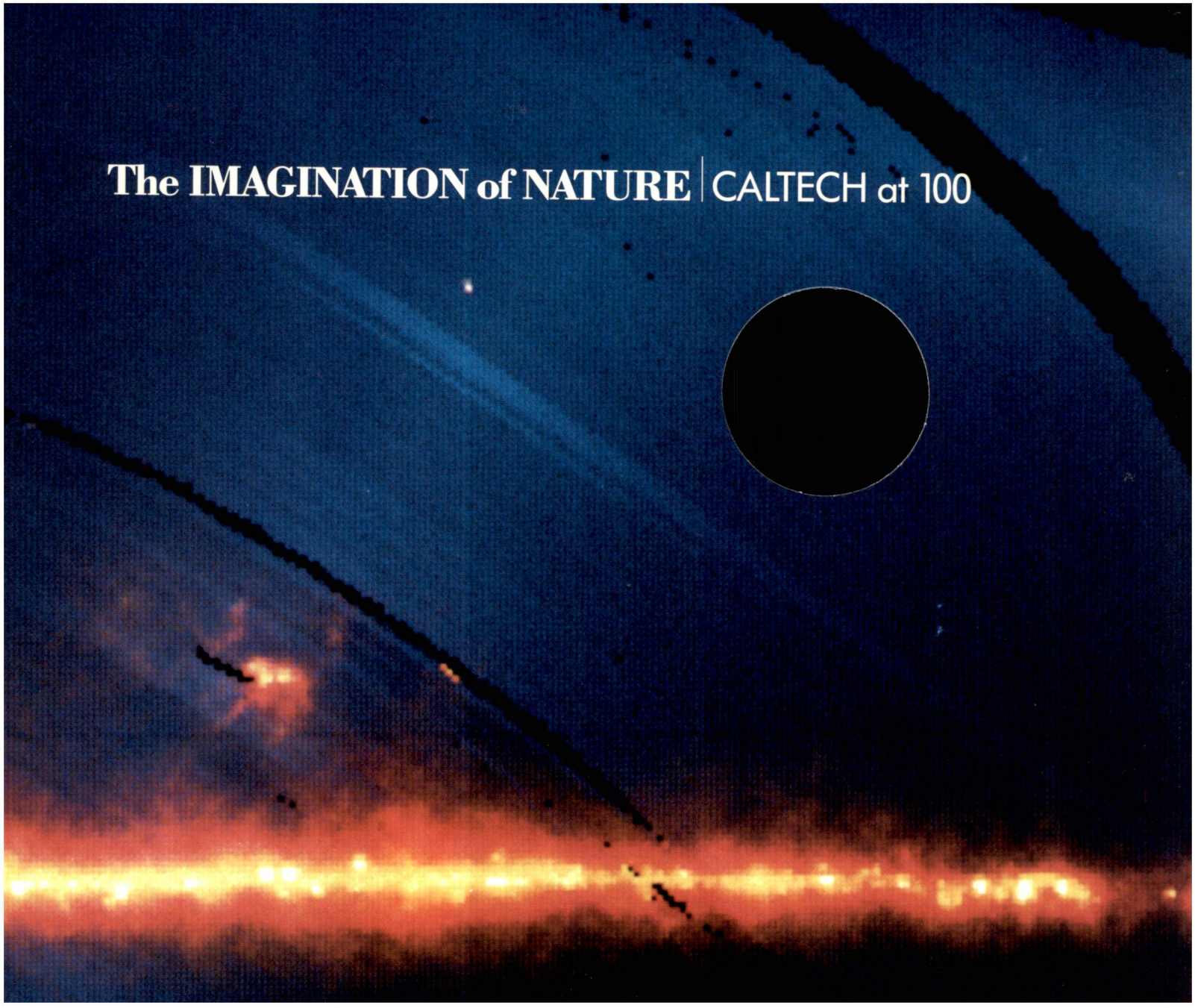
  This program provides funds to involve the resources of universities in economic development within the community.

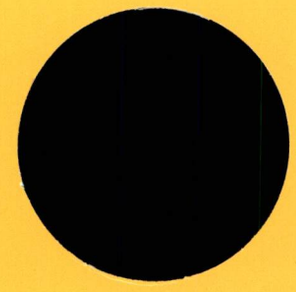
- NASA Industrial Applications Centers Program:

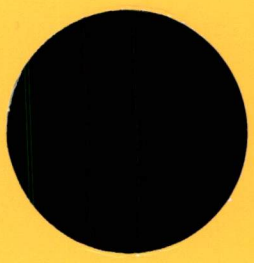
  The centers offer clients access to a national data bank that includes over 100 million documents of accumulated technical knowledge, along with their expertise in retrieving information and applying it in support of clients' needs. The centers are backed by state-sponsored business or technical centers that provide access to the technology transfer network.

- Trade Adjustment Assistance Centers Program:

  The centers provide trade-impacted small and medium-sized manufacturers with in-depth technical assistance.


The IMAGINATION of NATURE | CALTECH at 100



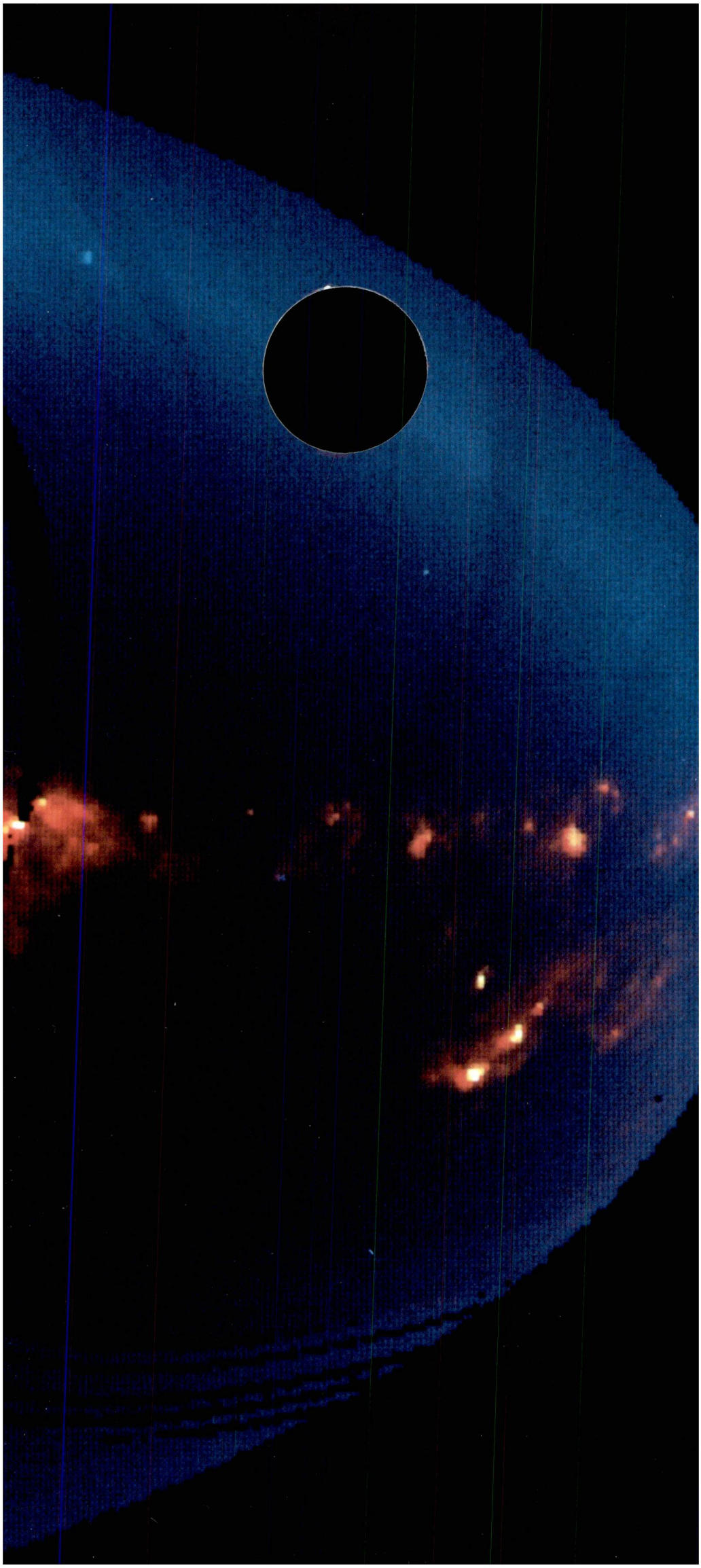


On the cover:

Nearly the entire sky, as seen in infrared wavelengths and projected at one-half degree resolution, is shown in this image, assembled from six months of data from the Infrared Astronomical Satellite (IRAS). The bright horizontal band is the plane of the Milky Way, with the center of the galaxy located at the center of the picture.

On the facing page:

A mechanosensory projection interneuron stained in an adult grasshopper by intracellular iontophoresis of cobalt hexamine. The diameter of the soma (lower right) is about 20 μm.
Photo: G. Laurent



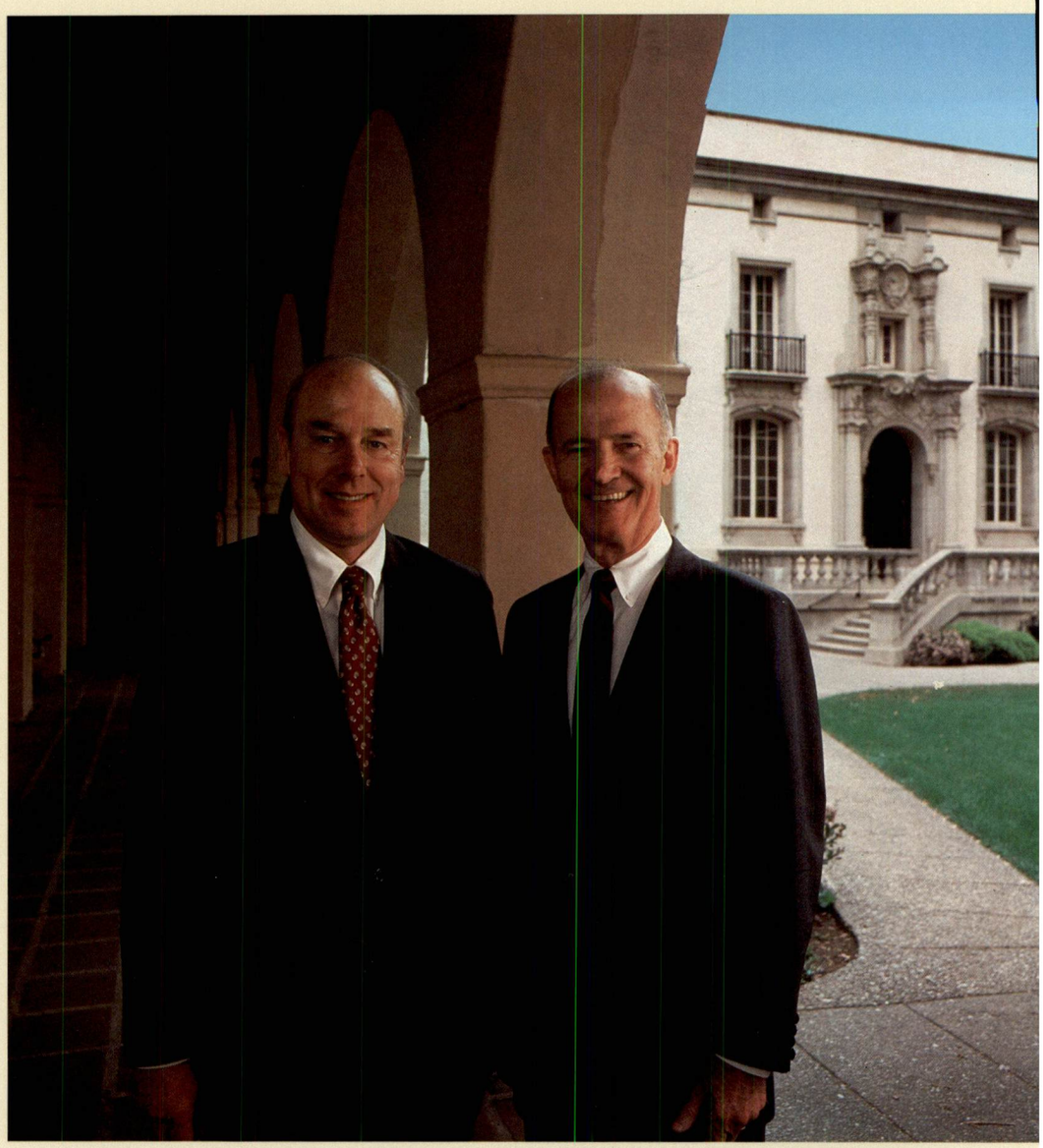


The imagination of nature is far, far greater than the imagination of man. . . . The same thrill, the same awe and mystery, come again and again when we look at any problem deeply enough. With more knowledge comes deeper, more wonderful mystery, luring one on to penetrate deeper still. Never concerned that the answer may prove disappointing, but with pleasure and confidence we turn over each new stone to find unimagined strangeness leading on to more wonderful questions and mysteries – certainly a grand adventure!

Richard P. Feynman

Nobel Laureate
Caltech Faculty Member, 1950–88
Richard Chace Tolman Professor
of Theoretical Physics, 1959–88

A COMMUNITY of DISCOVERY | The PEOPLE of CALTECH



Caltech is a century old—an instant of time in the history of humankind. Yet in that instant, Caltech has made substantial scientific, engineering, and technological contributions. These achievements have been acknowledged with the 21 Nobel Prizes, 29 National Medals of Science, and 2 National Medals of Technology awarded to Caltech faculty and alumni. At present, Caltech has on its faculty one of the highest percentages of members of the National Academies of Sciences and Engineering of any university in the nation. ⊖ The explanation for this amazing record lies in the very nature of the Caltech community. Caltech has brought together a small group of outstanding people and placed no barriers between them. Students and faculty work side by side, often beyond the bounds of traditional academic disciplines. Professional divisions have been minimized so that people and ideas may move more freely. In this environment of trust and integrity, people confront exciting and difficult problems; they explore new areas, instead of colonizing the old. In so doing, they have established an impressive tradition of intellectual daring. ⊖ Intellectual pursuits have gone hand-in-hand with practical applications. Early work in Caltech's high-voltage laboratory, for example, contributed to the development of the power industry in southern California. Its wind tunnels helped give birth to the aviation industry, its wartime rocket program to modern spaceflight. Its geologists and engineers have helped bring water to Los Angeles and keep buildings standing during earthquakes. And Caltech's electrical engineering and materials science research has produced innovations in the design of computers and integrated circuits. ⊖ Achievements and contributions—these are not relics of the Institute's past. Rather, they are milestones along a remarkable path of discovery, one that reaches into the future just as surely as it grows out of the past. Highlighted in the following pages are examples of research produced during the first century of Caltech's history. They by no means encompass *all* that Caltech does, but taken together they suggest Caltech's significance to our collective past, present, and future. The next section provides a brief outline of what it will cost to preserve this path of discovery into the Institute's second century. ⊖ The examples presented in this book provide only a sampling of the many contributions made to science, technology, and engineering by generations of Caltech students, alumni, and faculty. The people of Caltech—they are the reason our institution exists and why it deserves the highest levels of support.

Thomas E. Everhart

Thomas E. Everhart
President

Ruben F. Mettler

Ruben F. Mettler
Chairman of the Board

FOUNDATIONS of LIFE and MIND

Caltech's researchers look for answers to the riddles of life, growth, and disease at the most fundamental level—that of genes and the proteins they determine.

Thomas Hunt Morgan, the first chairman of the Division of Biology, identified the gene as a specific entity with a fixed location on a chromosome—an insight central to all subsequent work in genetics. He also recognized that life is fundamentally chemical. Thus, Morgan was instrumental in bringing to Caltech chemists, biochemists, and physicists to seek definitive answers to such questions as how a complex organism can develop from a single fertilized egg, how the body recognizes minute invaders it has never encountered before, and how the brain functions to make us thinking, feeling creatures.

Two of Morgan's recruits, physicist-turned-biologist Max Delbrück and biologist George Beadle, revolutionized our understanding of the nature and function of the gene. A contemporary of theirs, chemist Linus Pauling, helped confirm that genes direct the synthesis of enzymes, which then control the manufacture of the cell's proteins.

By working across disciplines, these faculty members and their colleagues helped lay the foundation for Caltech's current work at the frontiers of neuroscience, biochemistry, and molecular biology. The following examples provide a glimpse at some of the significant projects currently in progress on campus.

Seymour Benzer (a former postdoctoral fellow under Delbrück) is probing how genes control the devel-



Thomas Hunt Morgan, Pamela Bjorkman, Leroy Hood, Peter Dervan, and Seymour Benzer

opment and function of the nervous system. His work has yielded valuable insights, including the identification of the brain cells that selectively degenerate in patients suffering from Alzheimer's disease.

Peter Dervan is designing molecules that bind to specific sites on DNA. These molecules may one day help make it possible to map the spot where any given gene is encoded among the three billion chemical units that make up the blueprint of human heredity.

Using x-ray crystallography, Pamela Bjorkman is deciphering the three-dimensional structure of proteins crucial to the immune response. These so-called histocompatibility molecules bind to infected cells and signal the body's defenses to attack them. Knowing the proteins' structures may one day allow scientists to intervene at the molecular level to enhance the immune response, or prevent it from making mistakes, as in some forms of arthritis and diabetes.



Motivated by his research on families of genes related to the immune response, Leroy Hood has developed instruments to sequence and synthesize DNA and proteins. These instruments already have dramatically increased the productivity of biochemical research. In a single day biologists and chemists can now determine the chemical structure of complex molecules previously requiring teams of researchers many months.



Biologist Seymour Benzer's studies of the fruit fly Drosophila probe the foundations of life and mind – how does a single cell develop into a complex organism whose cells are exquisitely specialized? This micrograph of a larval Drosophila brain shows the axons of developing retinal nerve cells (stained with a fluorescent marker) fanning out toward the brain's visual center as the brain wires itself up.

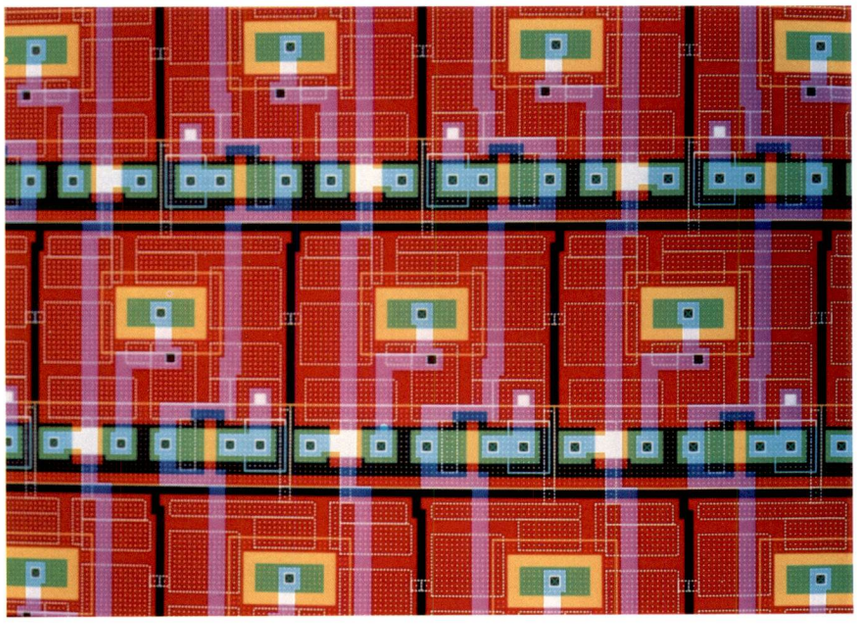
INFORMATICS and COMPLEX SYSTEMS



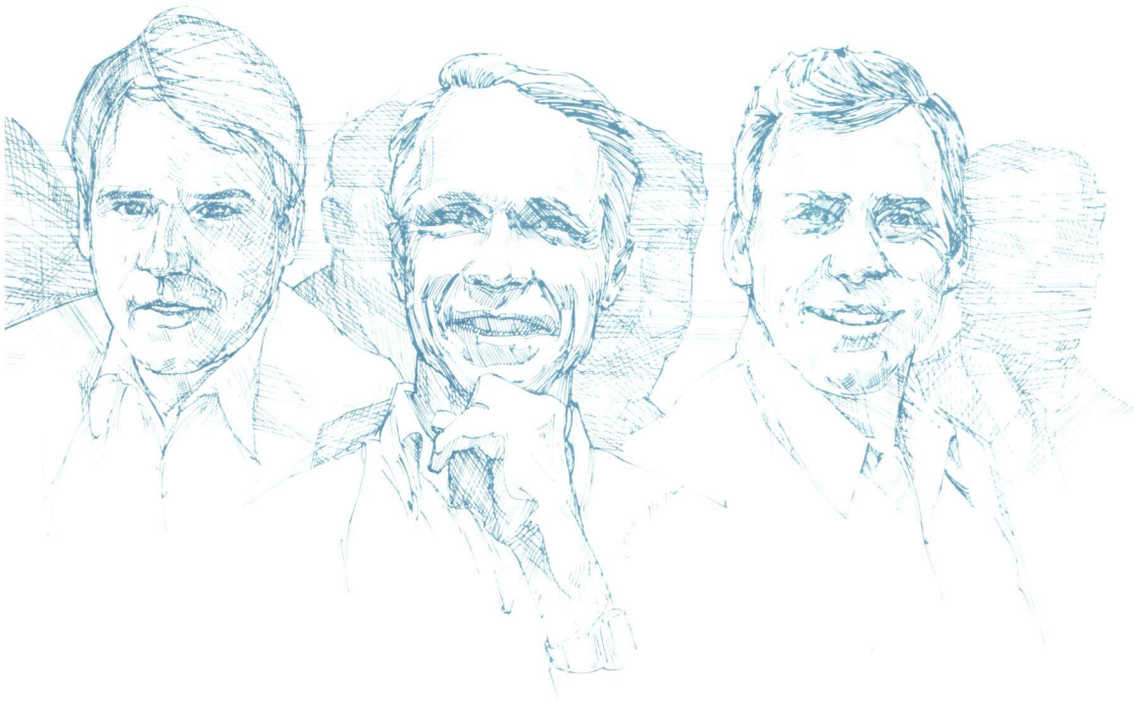
Information technology already drives a $750 billion industry worldwide; yet, surprisingly, this technology is still in its infancy. Through advances at every level of computing, from the design of integrated circuit chips to software that mimics human cognition, to large integrated systems, Caltech faculty are hastening a new relationship between this technology and its users. The computer will no longer be a mere implement but rather an assistant—and perhaps even an advisor—in our work.

At the center of these revolutionary developments is the silicon chip. Carver Mead predicted that chips could hold millions of computing elements; he then devised a way to design such chips. His approach became the industry standard. He also built the first gallium arsenide MESFET transistor, opening the way for a faster nonsilicon-based technology. Finally, Mead and a group of Caltech graduate students created a program for designing specialized chips from symbolic descriptions—the silicon compiler. *Forbes* magazine has predicted that this development may revitalize the American chip industry by speeding innovation. Important leaders of today's most advanced entrepreneurial ventures in chip design, and of large corporations developing information-based systems, have come from Caltech.

This retina chip, developed by Carver Mead and Misha Mahowald, is a first attempt to mimic in silicon-based hardware that which nature does so well in carbon-based "wetware." A housefly avoiding a swatter is solving a complex visual and kinematic problem with a speed and economy of effort that computer designers can only dream of. Biologically successful design principles, honed over millions of years of evolution, have much to offer the next generation of computers.



The Institute's path-breaking work in large-scale chips is complemented by the development of innovative computing systems and software—areas offering enormous potential gains in computing speed and productivity. In 1985, Charles Seitz and his



Carver Mead, Christof Koch, John Hopfield, and Charles Seitz

students developed the highly concurrent Cosmic Cube message-passing multicomputer, a novel approach to high-speed computing that has helped create a new segment of the computer industry. The latest products of his research are ultrafast message-routing chips and software for distributing parts of computing problems to ensembles of small, fast computers. These are being incorporated into the next generation of concurrent supercomputers.

Future computers may be modeled on biological systems. Mead and John Hopfield are part of a group that designs specialized chips and systems of chips, called neural nets, that process information (such as sight and sound) in a way more like the brain does than do traditional computers. Such neural nets promise to advance computing as dramatically as did the integrated circuit, and their ability to learn is being advanced by Caltech faculty. Mead has also developed a rudimentary retinal chip, while Christof Koch is searching for the computational principles that govern visual pattern recognition. As Caltech faculty begin to translate this knowledge into silicon, they take a step toward producing a truly intelligent machine.

As computers evolve, they change the way scientists work. Computer simulations of complex phenomena generate data that would be difficult to obtain in the laboratory. For example, Anthony Leonard is developing techniques to simulate unsteady-flow separation—e.g., the turbulent air caused by a spinning helicopter rotor—in three dimensions.

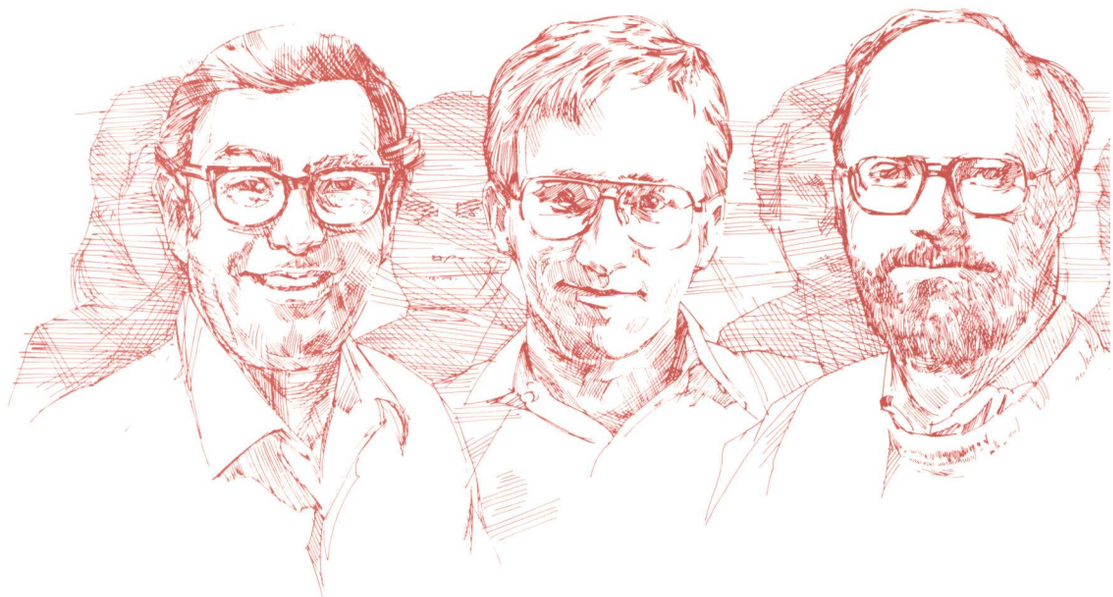
MOLECULES, MATERIALS, and MICRODEVICES

Plastic wires capable of conducting current, electronic devices no more than a few atoms wide, solar cells that might someday mimic photosynthesis: these technological marvels are taking shape at Caltech and elsewhere because scientists now design not only machines but the materials of which they are composed.

Caltech's early materials scientists were driven by practical problems. Just before World War II, Pol Duwez investigated what happens to metals subjected to sudden and intense shocks (explosions, for example). From Duwez's lab notes, aerodynamics expert Theodore von Kármán derived the complete theory of plastic-wave propagation, a major step in our understanding of how materials respond to stress.

Duwez went on to discover a new class of materials, metallic glasses, endowed with unusual electronic and magnetic properties, including resistance to radiation and corrosion. A group of Caltech researchers, including Thad Vreeland, William Johnson, and Brent Fultz, along with both undergraduate and graduate students, has devised a method for fabricating these materials in bulk, a precondition to studying many of their exotic properties.

The microchip revolution has motivated a quest for more efficient conducting materials to make possible supersmall, superfast electronic devices. William Goddard III, through his pioneering computer models of how bonds form between atoms and molecules in chemical reactions, is hastening the chemist's ability to design more complex molecules.

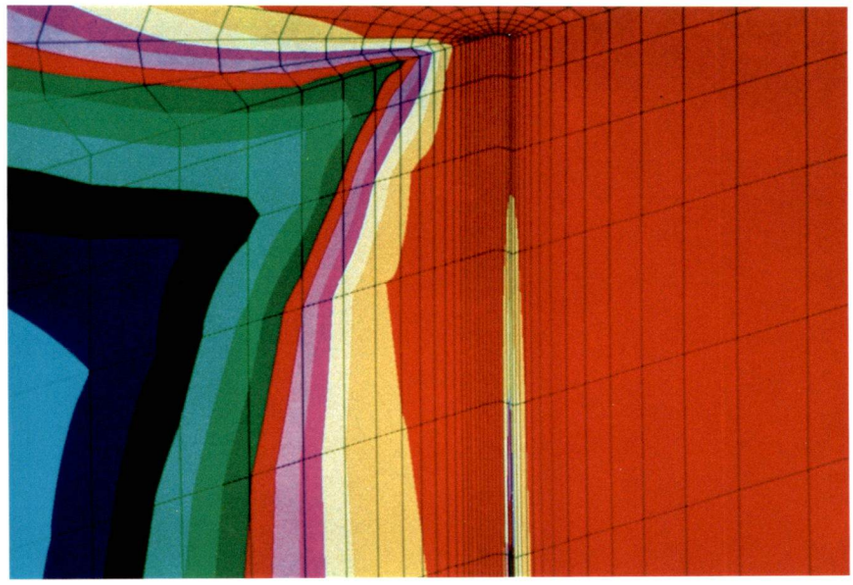


Harry Gray, Kerry Vahala, Robert Grubbs, and Pol Duwez

Robert Grubbs has perfected a new process for making polymers with properties that can be varied by molecular design. His group may eventually be able to create superlattices and composite materials containing different layers that are only a few atoms thick.

Will electronics, a field that was revolutionized by the invention of the transistor, eventually produce devices as small as a few atoms and capable of operating at the speed of light? Amnon Yariv has made a laser only 20 atoms thick that operates on virtually no current. A group led by Kerry Vahala has produced bumps of gallium arsenide a few hundred atoms thick with the capacity to emit light when stimulated by electrons.





Such electronic devices will still need energy to run them. Harry Gray's research into the processes whereby electrons move in metal-containing proteins such as chlorophyll could lead to a chemical system that harvests energy from sunlight the way that green plants do.

While most researchers seek new ways to put molecules and materials together, Ares Rosakis studies what happens when they come apart. This supercomputer simulation of a steel plate breaking shows stresses ranging from low (blue) to high (red). The crack is traveling from left to right. The yellow spike is the crack tip, where breaking bonds relieve local stress. Rosakis's group has developed high-speed methods to measure the stresses and temperatures surrounding a moving crack, which travels faster than a mile a second.

The UNIVERSE

From the farthest reaches of the cosmos to the innermost workings of the atomic nucleus, Caltech scientists probe the origin, evolution, and destiny of the universe.

During Robert Millikan's tenure as administrative head of the Institute (1921–45), Caltech became a world-class center for the study of physics and astronomy. Millikan illuminated a basic constituent of matter, the electron. A former student of his, Carl Anderson, deepened our understanding of the universe and matter by discovering the first antimatter particle, the positron.

Since those early years, Institute faculty members have continued to ask the most searching questions about the nature of physical reality. Richard Feynman completely restructured a major branch of modern physics called quantum electrodynamics. Murray Gell-Mann developed a theory describing the building blocks of matter, which he dubbed quarks; their existence was later demonstrated by experiment. His discovery opened up new avenues of research in subatomic physics, clarified the nature of the "strong force" that holds protons and neutrons together in the atomic nucleus, and pointed the way to a better understanding of what occurred in the first instants of the big bang, the explosion that gave birth to the universe.

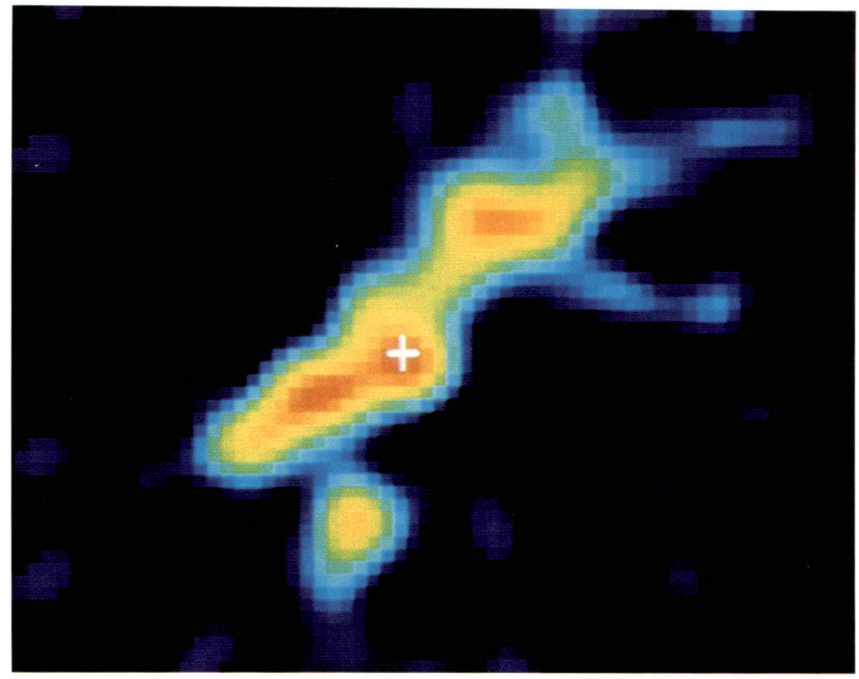
Following in the tradition of the great astronomer George Ellery Hale, Caltech physicists, astronomers, and astrophysicists have built sophisticated instruments to explore our dynamic universe. With them, Institute scientists have discovered the



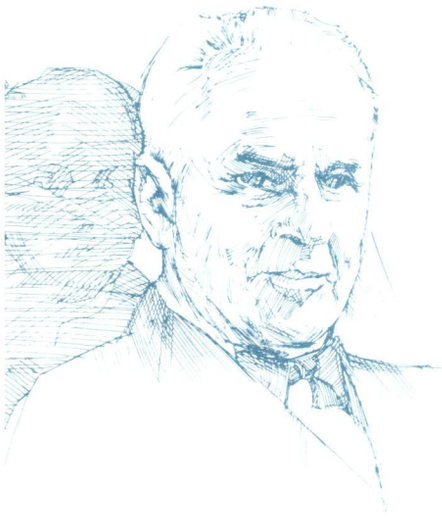
Gerald Wasserburg, Kenneth Libbrecht, Murray Gell-Mann, and Robert Millikan

universe's oldest and most distant objects, identified nearby stars that may be forming their own solar systems, and explored the planets. Closer to home, Kenneth Libbrecht has compiled research data that provide a surprisingly complex picture of the internal dynamics of the sun.

Caltech geologists, too, are looking outward to answer basic questions. Clues to the origin of our solar system are scattered across billions of miles. Gerald Wasserburg has been comparing isotopes in moon rocks and interplanetary debris in an attempt to describe the early chemical and physical evolution of the solar system.



HL Tauri is a nearby sunlike star that is younger than our own. This image, made by Steven Beckwith and Anneila Sargent with the millimeter-wave interferometer at Caltech's Owens Valley Radio Observatory, shows the gas cloud orbiting HL Tauri that may eventually condense into planets. Although no planets have yet been detected outside our own solar system, astronomers believe that planetary formation is a common process throughout the universe.



EARTH and ENVIRONMENT

Throughout Caltech's history, its scientists and engineers have studied the environment in the broadest possible context, expanding our awareness of the forces that shape it, and of our impact upon it.

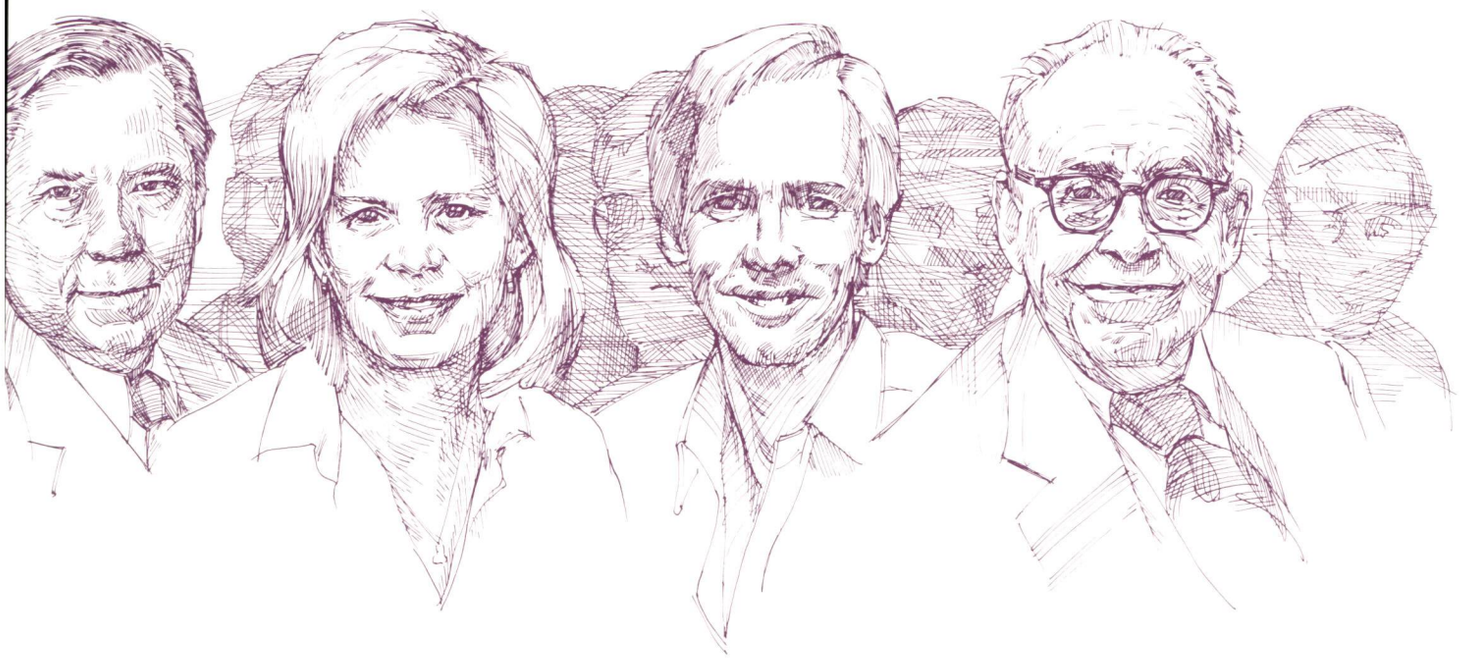
Caltech has pioneered far-reaching investigations and innovations in earthquake science. In the 1930s, Charles F. Richter joined with Beno Gutenberg to devise the first instrumental method for measuring the energy of earthquakes—the Richter scale. In so doing, they helped develop modern seismology. Today, geologist Kerry Sieh is adding to our understanding of earthquakes through the precise dating of recent great earthquakes along the San Andreas Fault. The new dates he has established present an intriguing pattern—a cluster of two or three major shocks within a century or so, separated by two to three centuries of quiet.



Preparing for earthquakes and finding ways to minimize their potential danger to life and property interests earthquake engineers at Caltech. George Housner, known as the "father of earthquake engineering," has developed with other Caltech faculty the design recommendations that have resulted in some of the first earthquake building codes based on modern engineering principles. Housner headed the California commission investigating the collapse of the Nimitz Freeway during the 1989 Loma Prieta Earthquake, which struck the San Francisco Bay area.

Antarctic ice moves toward the sea with glacial slowness—perhaps a dozen feet per year. "Ice streams" tens of miles wide, however, move several feet per day—as much as 100 times faster than the ice sheet around it. A stream is marked from the air by the jumbled, churned-up belt of ice along either margin (a cloud shadow crosses the stream in the middle distance). Geologist Barclay Kamb's studies may show if the Antarctic ice sheet is breaking up, a possible consequence of climatic change.





John Seinfeld, George Housner, Mary Lidstrom, Kerry Sieh, and Charles Richter

In the late 1940s, Arie Haagen-Smit conducted basic research that first identified the components of smog. His discoveries provided the groundwork for Caltech's current work in the chemistry and physics of air pollution. John Seinfeld has developed detailed mathematical models of pollutant behavior in the atmosphere. Now part of the Federal Clean Air Act and in use by the state of California and the Environmental Protection Agency, these models make it possible to examine the hypothetical consequences of reducing levels of emissions.

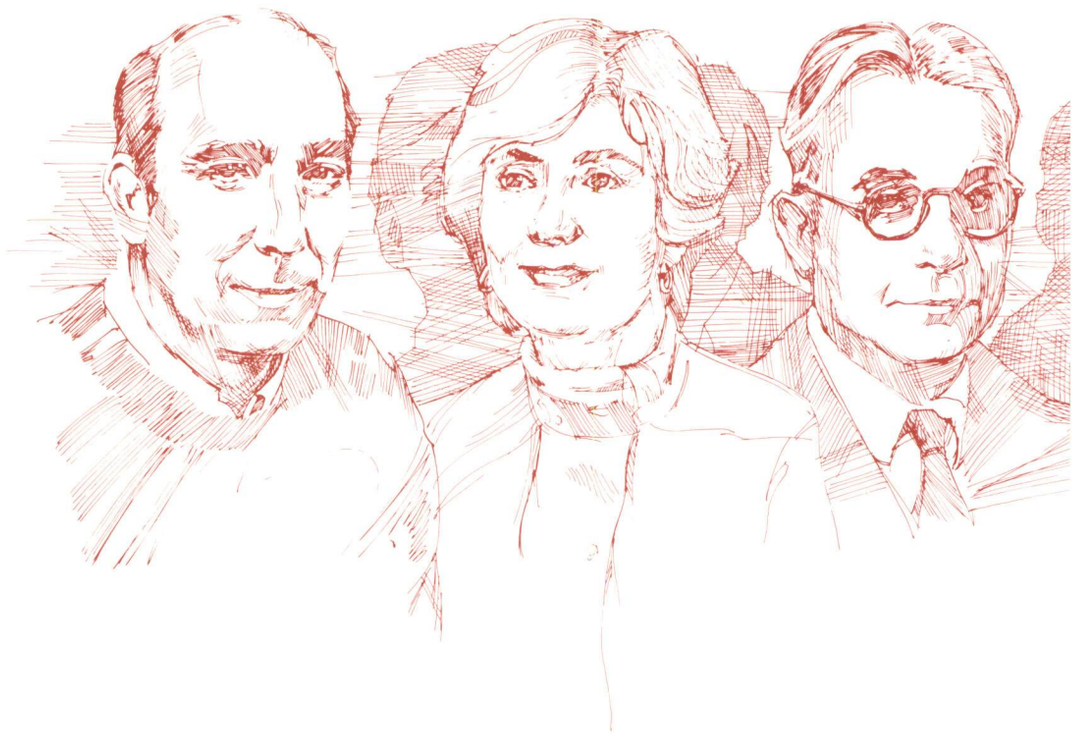
Real solutions to environmental problems must undo damage without creating further disturbances. A potential path to this necessary condition is being explored by Mary Lidstrom. Her approach makes use of naturally occurring bacteria that are capable of consuming chlorinated hydrocarbons, a major class of groundwater pollutants. She and her students are using advanced microbiological techniques to identify the genetic roots of this capability. Her goal is to make it possible to apply these and similar organisms to some of our most serious pollution problems, thereby tapping nature's own potential for self-renewal.

HUMAN VALUES and INSTITUTIONS

From its early days, Caltech has placed scientific and technical education in the context of other human activities. In 1921, the trustees established the requirement—unique in any engineering college at that time—of four consecutive years of study in the humanities for all undergraduates. Historian and political scientist William Munro, who joined the faculty in 1927, played an especially important role in the development of this program, securing endowment for the humanities and reshaping the undergraduate humanities curriculum. Today, Caltech undergraduates spend 20 percent of their course time studying the humanities and social sciences.

Munro's vision has been carefully guarded over the years and has, in fact, been strengthened by the appointment of outstanding faculty members who contribute their scholarly expertise to their Caltech students and their professional peers. Historian Eleanor Searle has brought a new understanding to the Norman period with the research she published in her book *Predatory Kinship and the Creation of Norman Power, 850–1066*. Literature professor John Sutherland studies publishing and printing in Britain and America from the inception of printing to the present day.

Classroom studies are further enriched by Caltech's program in Science, Ethics, and Public Policy. The program introduces students, faculty, and staff to informed thinking on issues related to the development of science and its engineering applications, in a socioeconomic and political context; the ways science and technology shape, and are shaped by, public policy and bureaucratic practice; and the moral and ethical issues related to the uses of science and technology.



Daniel Kevles, Eleanor Searle, William Munro, Thomas Palfrey, and Charles Plott

The program was developed by Daniel Kevles, who is now collaborating with Caltech biologists to examine the moral implications of modern biotechnology and its potential applications.

Investigators led by Charles Plott, working in Caltech's Laboratory for Experimental Economics and Political Science, have pioneered innovative techniques that have made it possible to examine the validity of various political and economic theories under controlled laboratory conditions. Studies that Plott and his colleagues have carried out over the last 15 years have had a direct impact on policy making in the public and private sectors in such areas as interstate commerce and transportation.

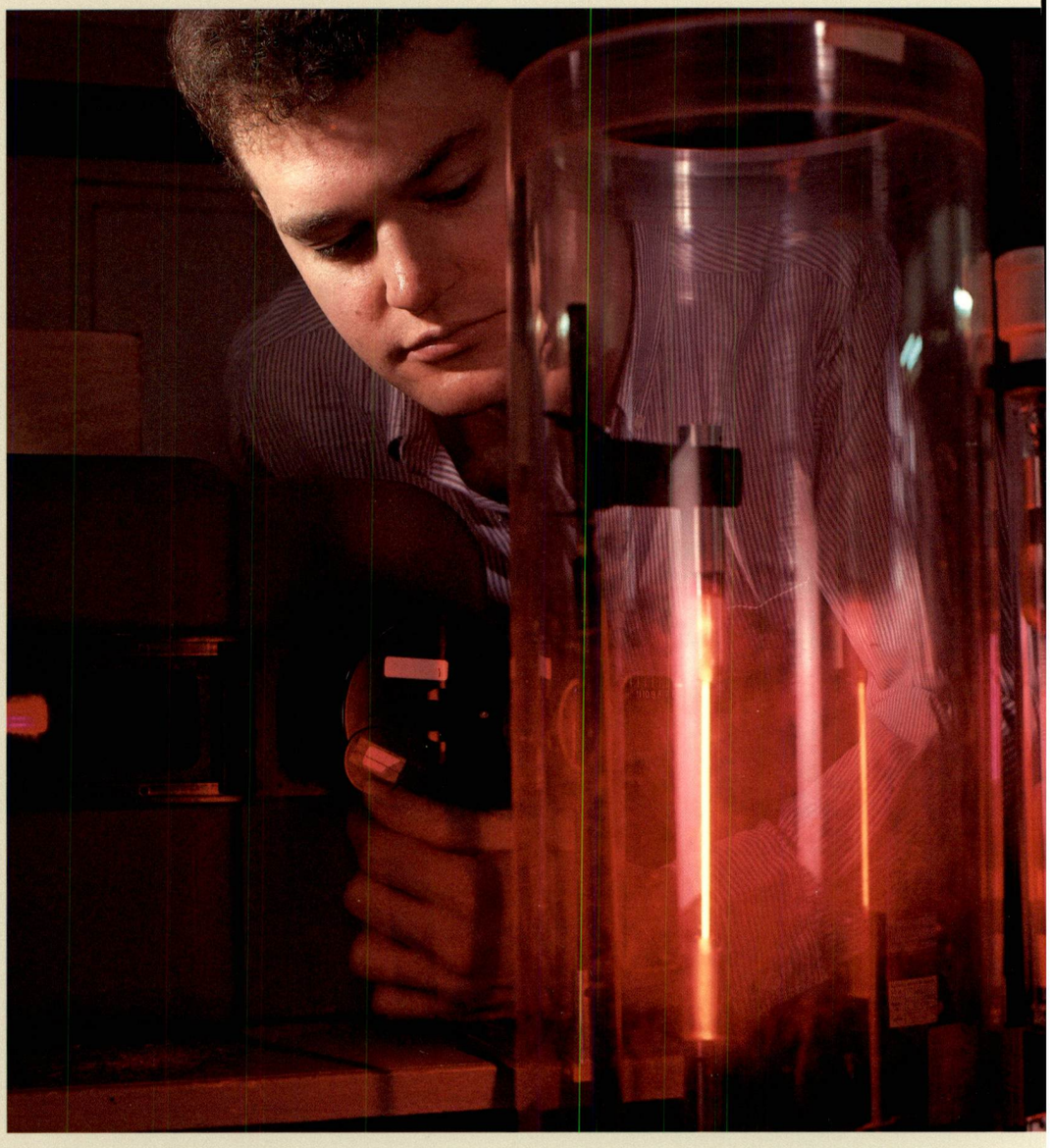
Thomas Palfrey has been using similar experimental techniques together with theoretical models to study a wide range of problems, from the effects of futures markets and insider trading on asset price volatility, to a comparative study of different procedures for eliciting voluntary contributions. He has also been studying the theoretical foundations for the design of incentive schemes, with applications to cartel behavior, voting rules, auctions, and multilateral contracting.



"The Duke's vessel lands at Pevensey" is part of the famed Bayeux tapestry, embroidered in the Middle Ages as a record of the Norman conquest of England. Recent studies by historian Eleanor Searle indicate that the medieval Norman state was built on a complicated network of kinship alliances. Kin loyalty was added to the more fragile bonds of chosen leadership, resulting in a group of cousins-by-marriage that could not only defend itself against French threats, but could (and did) see to it that no other, unallied group flourished in Normandy.



The PRICE of DISCOVERY | The FUTURE of CALTECH



The achievements presented here were made in an intimate, unfettered community of discovery. Over the decades, this Caltech community has required significant resources to maintain such a high level of productivity. With the increasing competition for public funds, the urgent question arises: who will step forward to assure that the most daring work in engineering and science can continue, the kind of work upon which our competitive future as a nation depends? ⊖ Government support for fundamental scientific research has increased significantly in the past half-century. That commitment, as well as support for engineering and education, has fluctuated with policy objectives. The excellence of Caltech's work has earned it a generous share of such support, but such success may prove to be a mixed blessing. Grants from public sources are becoming smaller, their duration shorter, their stipulations and constraints more cumbersome. Less and less do they allow for the fluid, farseeing exploration that is Caltech's hallmark, or for the costly process of training tomorrow's innovators to think in the Caltech way. ⊖ The key issue remains the price of innovation—and the cost of its neglect. If narrow notions of cost-benefit limit our best minds to doing only what they have successfully done before, then true innovation may cease and the greatest advances might well elude us. Caltech's leadership in innovation represents a practical and an intellectual resource that the nation cannot afford to lose. ⊖ Such a loss is unthinkable to those who value Caltech. They understand that money invested in Caltech is venture capital for the highest-quality work in science and engineering. Thus private donors have helped underwrite the construction of Caltech's buildings, supported Caltech students with scholarships and fellowships, and sponsored a range of research projects. Many of Caltech's most ambitious current enterprises, including the construction of the world's largest optical telescope and of an institute dedicated to developing new technologies to spur discovery in biology and chemistry, were made possible by significant commitments from private sources. ⊖ Tomorrow's bold scientific achievements will depend on equally bold philanthropic commitments. At Caltech, the two go together, for trust and conviction motivate the philanthropic investment—trust in the power of human intelligence and conviction that ideas can transform our lives for the better. A century of achievement at Caltech is powerful evidence that donors with this trust and conviction are the most farseeing and astute of investors.

UNDERGRADUATE EDUCATION



My four-year experience at Caltech revolutionized the way I thought about science, society, scientific endeavors, and myself. Although one might argue that any rational person would react that way to the "college experience" in whatever setting, I would argue that my conclusions were different from those I would have drawn from attending any other university. After I left Caltech, I found that my approach to problems, my standards and expectations, certainly set me apart from a good many of my fellow graduate students. In short, whenever anyone asks me, "Where did you go to college?" I am always tempted to say, "I didn't, I went to Caltech."

Madeline A. Shea (B.S. '77)
Presidential Young Investigator
Assistant Professor, Biochemistry
University of Iowa

Caltech's 800 undergraduate students are among the most gifted and talented in the country. As Caltech students, they benefit from a student/professor ratio of 3:1, perhaps the nation's lowest. They learn science and engineering by working in labs with outstanding faculty. In the process they also experience the excitement of being at the intellectual cutting edge of their chosen fields. Their accomplishments in this environment are impressive, from the discovery of a distant supernova to the development of techniques for fabricating new industrial materials. As graduates, they become leaders in science, engineering, business, and medicine. Indeed, they make it a matter of national interest that the academic community of Caltech be maintained.

The task requires considerable financial commitment. First, to preserve the low student/professor ratio, Caltech has resisted income-generating increases in enrollments, just as it has resisted dependence on graduate students for much of its instruction. Second, Caltech provides extensive opportunities for conducting independent research under the supervision of faculty. To take but one example, Caltech has expanded its highly successful program of Summer Undergraduate Research Fellowships (SURFs) from an original 18 to more than 100 students annually at a cost exceeding $600,000. One of the Institute's primary goals is to make similar opportunities available to more Caltech students. Finally, Caltech admits students without regard to their financial means, then works with them and their families to meet their demonstrated need.

Given the cost of such commitments, can Caltech remain affordable and accessible? Several factors threaten those qualities.

At Caltech, as elsewhere, the cost of education has been rising steadily. That rise has been fueled by a number of factors, including changes in teaching and research technologies and the need to modernize old facilities, from student houses to labs. Increased costs have been partially reflected in increased tuition. Yet in the last decade, federal support for student financial assistance has steadily decreased. Two-thirds of Caltech's undergraduates currently receive need-based financial aid, and the Institute funds an increasing percentage of the cost. If Caltech cannot maintain this level of support, it may not be able to accept many excellent students.

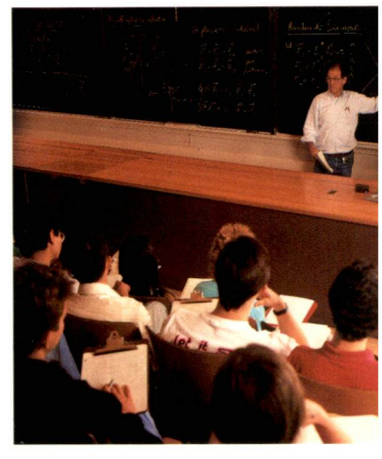
In a sense, any private gift that reduces the educational cost to the student—no matter how indirectly—will help preserve the character and educational effectiveness of Caltech. In four areas, however, private support can have a direct impact: financial assistance to students, undergraduate research opportunities, the upgrading of student housing, and the expansion



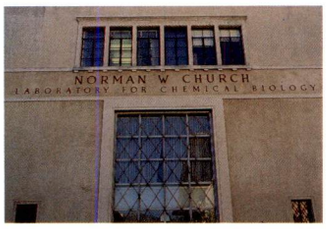
Two-thirds of Caltech's undergraduates receive need-based financial aid. Caltech admits students on the basis of talent and their interest in science and engineering, without regard to their ability to meet the full costs of attendance.

of athletic facilities. Without private support, Caltech will eventually be forced to choose between those areas. Students discouraged from coming to Caltech because their financial needs cannot be met or because facilities are outmoded represent potential that may go unfulfilled at a time when the nation needs high achievement in science and engineering. America's best and brightest deserve the opportunity to excel; private support can guarantee them that chance.

The small student-to-professor ratio (3:1) provides many opportunities to interact with faculty, in the classroom and lab.



GRADUATE EDUCATION



When I began my courses at Caltech, I thought I had made a terrible mistake. I had thought my study of science was behind me and what I needed was to become expert at applying science to the design of real-life electrical equipment. My eyes were opened to a whole new concept of how to prepare for a career in the application of science. . . . Innovative engineering consists in part in inventing new ways to put well-established principles to work. But a large part of what engineering is about, I came to see, is the exploiting of new knowledge as soon as possible after it is uncovered. It's like the difference between learning how to pump oil ever more efficiently from an existing well and finding new oil deposits. Caltech taught me how to make discoveries.

Simon Ramo (Ph.D. '36)
Caltech Life Trustee
Co-Founder and Director
Emeritus, TRW Inc.

If the United States is to maintain its international leadership in science and its competitiveness in advanced technology, if it is to meet the challenge of human health and assure clean air and water, it must encourage potential graduate students to enter degree programs in the sciences and engineering. Moreover, it must challenge them to ask new and penetrating questions and assume intellectual as well as professional leadership. Caltech has created an environment for graduate study in which such challenges are central.

At Caltech, graduate students can concentrate on the primary goal of their education—establishing themselves as independent investigators. The total Caltech faculty—which includes postdoctoral fellows as well as professorial, research, and visiting faculty—nearly equals the number of graduate students. Thus, these students are certain to be working closely with outstanding scientists and engineers.

The most important dimension of graduate education at Caltech, however, is intellectual responsibility. Graduate students are essential to the research conducted by Caltech faculty. They are treated as colleagues and members of a team. When they graduate, they are prepared to make a difference rapidly, and their record of achievement speaks for itself. Caltech doctoral graduates occupy leadership positions in academia, industry, and government.

Because of Caltech's importance in training the next generation of scientific and engineering leaders, it is essential that the Institute recruit and support the most outstanding graduate students. As with its undergraduates, Caltech must meet keen competition to maintain the caliber of its graduate student body. Because a graduate student's choice of schools is strongly influenced by economic factors, first-year fellowships are critical to Caltech's ability to attract the very best science and engineering students. Graduate students are frequently supported by federal research grants, a funding pattern that leaves many good students—particularly those with special needs or in areas underfunded by the federal government—in need of private support.

The Institute's continued ability to attract and support outstanding graduate students therefore depends on adding to the current endowment for graduate fellowship support.



Working as independent investigators, Caltech graduate students prepare themselves for future leadership positions in academia, industry, and government.

Graduate students have the opportunity to do their research at such off-campus facilities as Palomar Observatory.



POSTDOCTORAL STUDY



When you put a lot of powerful intellects together in one place, the chances are almost nil that they will consistently agree with each other. Caltech is small enough, and the people here know and respect each other well enough, that they feel free to disagree. That generates a tremendous amount of intellectual energy. When I first arrived on the Caltech campus, I saw Albert Einstein and Robert Millikan heatedly debating on the steps of Throop Hall. I said to myself, "This is where I belong."

William A. Fowler (Ph.D. '36)
Nobel Laureate
Caltech Faculty Member, 1936–
Institute Professor of Physics, Emeritus, 1982–

Caltech's contributions to science and engineering depend on protecting and nurturing its community of scholars, one in which faculty, undergraduate and graduate students, and postdoctoral fellows all play a vital role.

With the increasing pace and complexity of research, postdoctoral fellows have become especially important members of the research community in many fields of inquiry. They perform a vital function as mentors to both graduate and undergraduate student researchers. They are, at the same time, a key means by which the range of research and intellectual activity on campus is extended.

In return for these critical contributions, Caltech faculty guide postdocs through the crucial final stage of their scientific training, the final preparation for their careers as research scientists and engineers. Many postdocs do their most creative, "breakthrough" work during this period, before they take on the additional responsibilities of teaching and administration that come with professorial appointments.

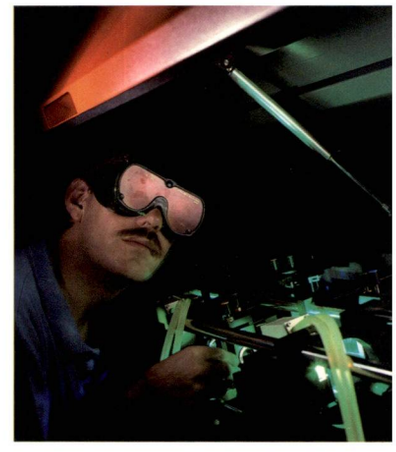
The cost of maintaining this element of the Caltech community is anywhere from $28,000 to $40,000 per fellow per year, as well as a large amount to maintain the facilities in which postdocs work. Some of that money comes from private contributions, but at present the bulk of it derives from public sources, usually federal grants.

Federal funding for postdoctoral fellows varies greatly from field to field and, as with faculty and students, the best individuals are in great demand. Endowed funds to support postdoctoral fellowships will ensure that the Institute can continue to attract and support outstanding fellows in many important fields.



Postdoctoral fellows and their faculty advisors establish a research environment in which new ideas are developed and explored. Together, they are the leaders of research projects that also include graduate and undergraduate students.

Endowed postdoctoral fellowships permit outstanding young scientists and engineers to conduct advanced research projects at Caltech.



RESEARCH



Caltech has been and remains the most exciting center in the world for science and its closely associated technologies. One reason is that the Institute itself is small, even while it operates the giant engineering activities at the Jet Propulsion Laboratory. The preeminent quality of its students, its faculty, and of the research program at Caltech assures a continuation of the Institute's long record of Nobel Prize winners, of widening the frontiers of science, of creating new technologies and even entire new industries. It is indeed at the same time a national resource and a world treasure.

Harold Brown
Caltech Trustee
Caltech President, 1969–77
Secretary of Defense, 1977–81

Over the history of the Institute, Caltech scientists and engineers have extended humankind's field of vision and capacity to alter the world for the better. They promise to extend both even further in the decades ahead as they design computers that are orders of magnitude faster, probe the heavens with the world's largest optical telescope, and design robots that can "see."

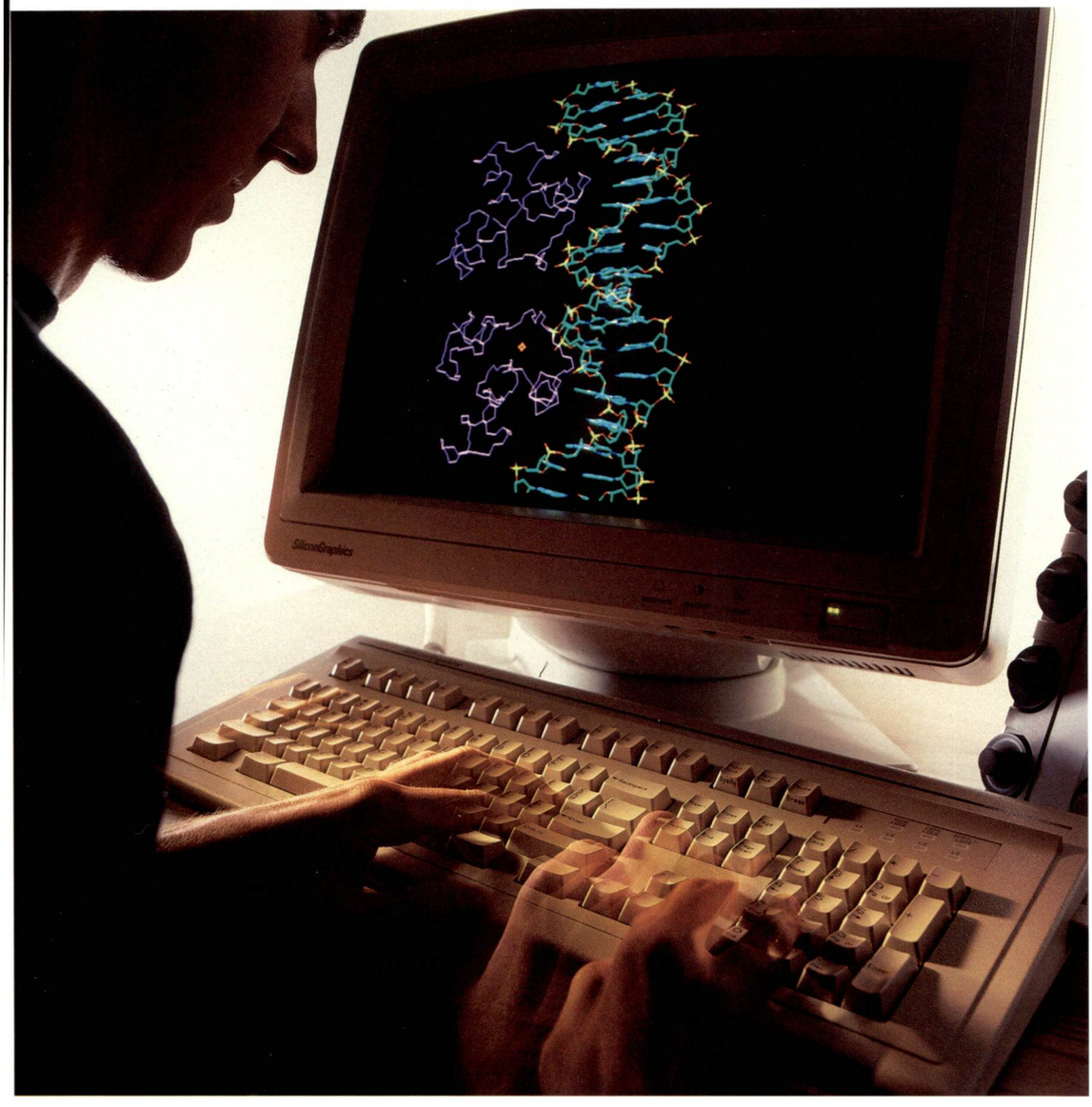
A major impediment to these breakthroughs would be the loss of scientific independence. As a private institution, Caltech exists to foster that independence. The freedom to pursue ideas wherever they lead has made Caltech one of the world's premier academic institutions. But guaranteeing that intellectual independence is costly. It cannot be done without significant private support.

The federal government does not fund the creation of research infrastructure on university campuses. At Caltech that infrastructure—primarily buildings—has been created almost entirely from private contributions. Major gifts have demonstrated that no intellectual challenge is too daunting when met with the resources of private philanthropy. Yet, apart from those initiatives, Caltech still faces significant capital needs to support research. These range from completely new facilities to renovated laboratories.

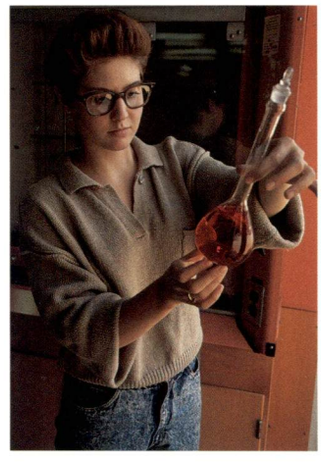
In addition to funds for capital projects, Caltech also needs direct private investment in research programs. Several factors make that need urgent. Currently, almost 60 percent of Caltech's operating budget is supported by the federal government. Grants from such agencies as the National Science Foundation help defray the costs of salaries, equipment, support staff, and maintenance. Because of the quality of Caltech's work, the level of federal support is unusually high. Thus, Caltech's very success has made it vulnerable to cutbacks and changes in federal funding policies.

The more research Caltech is able to support from its own and private sources, the greater will be its freedom from the effects of federal budgetary fluctuations. More important, increased direct private support will also guarantee Caltech's ability to set its own research agenda: to expand its research facilities, purchase and develop new equipment, assist new faculty with start-up funds for their laboratories, and launch promising projects.

Most important, private support will enable Caltech faculty to follow the path of imagination rather than that of conformity. That path is often complicated, and its payoffs are never guaranteed, but as we look back on Caltech's contributions from a world greatly altered by them, we recognize that path as ultimately the most efficient and productive possible.



Sophisticated computer technology enables researchers to design experiments that may unlock the secrets of human heredity.



Summer Undergraduate Research Fellowships (SURFs) are granted to more than 100 undergraduates, who devise their own research projects.



In 1891, Amos G. Throop, a Pasadena businessman, founded the modest school of arts and crafts—Throop University—that later would become Caltech. An important step in this transformation was made shortly after the turn of the century by Throop trustee and noted astronomer George Ellery Hale, who changed the focus of the school to the training of outstanding scientists and engineers.



"Father" Amos G. Throop, founder of Throop University.

Throop was renamed the California Institute of Technology in 1920. The next year, the distinguished physicist Robert A. Millikan (who had been persuaded by Hale and chemist Arthur Amos Noyes to come to Pasadena in 1917) became the Institute's first administrative head. This event initiated one of the most rapid rises to prominence of any institution in the country. Two years after his appointment, Millikan was awarded the Nobel Prize for his work determining the charge on the electron.

In the 1920s, the Seismological Laboratory was established. This was part of the development of seismology into the international science of detecting, measuring, and studying earthquakes. In the 1930s, Charles F. Richter and Beno Gutenberg invented the Richter Scale for measuring quake energy. Today, the Seismological Laboratory continues to be one of the premier centers for earthquake study. In the 1960s, modern earthquake engineering also emerged as a field at Caltech. George Housner and his coworkers developed methods that have helped in creating codes for earthquake-resistant tall buildings, in Los Angeles and other seismically active areas.



Charles Richter by the Seismological Lab's recording drums in 1970.

In 1926, Caltech established the Guggenheim Graduate School of Aeronautics (now known as the Graduate Aeronautical Laboratories, or GALCIT), and in 1929, built the lab associated with it. In 1930, Theodore von Kármán joined the Caltech faculty. Under his direction, researchers at GALCIT developed



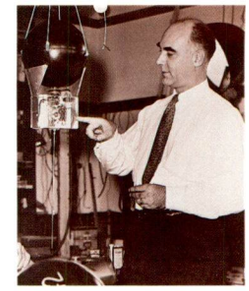
The California Institute of Technology educates approximately 800 undergraduate and 1,000 graduate students each year. Nearly 1,000 faculty members are in residence, including 280 professorial faculty, 380 research faculty (including 290 postdoctoral fellows), and 300 visiting and other faculty. Many of the Institute's 17,000 living alumni have achieved positions of leadership in science, engineering, business, government, and industry. The campus is situated on 124 acres and includes among its 100 structures some 40 laboratory and research buildings equipped with the latest scientific instrumentation. The newest and largest research facility is the Beckman Institute, whose unique mission is to accelerate discoveries in biology, chemistry, and related sciences by developing and applying inventions of methods, materials, and instrumentation.

principles of flight that helped launch the aircraft industry in California. In 1962, von Kármán was awarded the first National Medal of Science for his outstanding contributions to the development of science and engineering. Since then, 28 more Caltech faculty and alumni have received this highest national award for scientific achievement.



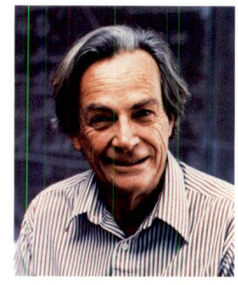
Theodore von Kármán receiving his award from President Kennedy.

The work of Caltech engineers impacted the growth of California in other ways. In the 1930s, 1940s, and 1950s, they played a crucial role in the design and construction of high-voltage transmission systems and of major irrigation projects in California. They established the High Voltage Laboratory and the Pump Laboratory and helped develop the pumping systems, aqueducts, and electrical components to bring water and power to Los Angeles.



Carl Anderson

In the 1930s, Caltech became a world center for the study of physics, a position it continues to hold. During those early years, Albert Einstein was a visitor on the Caltech campus, and Robert Oppenheimer served as a faculty member. In 1934, Carl Anderson discovered the anti-electron, or positron, the first empirical proof for the existence of antimatter. He was awarded the Nobel Prize in 1936. Richard Feynman joined the Caltech faculty in 1950, after completing his revolutionary work in quantum electrodynamics, work that earned him the Nobel Prize in 1965. At Caltech he expanded on these discoveries over a career of nearly 40 years, during which time he completely revised the teaching of undergraduate physics. Feynman was a key member of the Presidential Commission that investigated the 1986 explosion of the space shuttle *Challenger*.



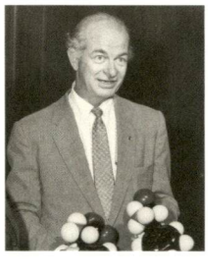
Richard Feynman

In the early 1960s, as problems developed with the accepted explanations of nuclear phenomena, Caltech physicists Murray Gell-Mann and George Zweig determined that protons and neutrons, long considered the fundamental building blocks of matter, were made up of even smaller particles, which Gell-Mann called quarks. Their theory was confirmed five years later, opening a new chapter on our knowledge of the atom. In 1969, Gell-Mann was awarded the Nobel Prize for this and other seminal discoveries. In 1984, John Schwarz and Michael Green proposed the "superstring" theory, which may prove to be the single unifying theory of elementary particles and forces that has long been sought by physicists.

Caltech displayed its determination to focus on "frontier" disciplines by bringing together a group of scientists who helped usher in molecular biology in the 1930s and 1940s. Thomas Hunt Morgan, who established the links between heredity and genes, won the Nobel Prize in 1933. George Beadle, who arrived at Caltech in 1935, made a group of discoveries that greatly expanded our understanding of the function of the gene; his discoveries included the pivotal notion that genes direct the formation of enzymes. He was awarded the Nobel Prize in 1958. Max Delbrück revolutionized the study of biology by bringing to it the techniques and perspectives of physics; his work earned him the Nobel Prize in 1969. Among the postdoctoral fellows during the 1930s was Jacques Monod, who had come to Caltech to study molecular biology. He was awarded a Nobel Prize in 1965.



George Beadle



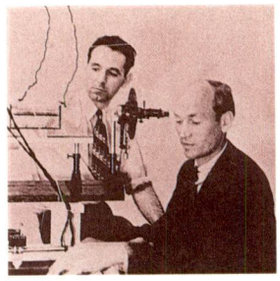
Linus Pauling

One of the most important discoveries in the history of chemistry was made at Caltech in the 1930s by Linus Pauling, who determined the nature of the chemical bond—how atoms link up to form molecules in both living and nonliving systems. Major advances in chemistry and molecular biology, and the creation of hundreds of synthetic products, had their roots in this single discovery. Pauling won the Nobel Prize twice: for chemistry, in 1954, and for peace, in 1962.



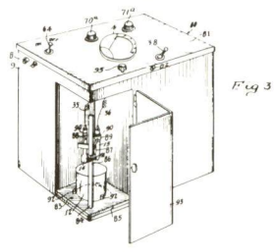
Caltech also operates the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. The world's leader in unmanned planetary exploration, JPL grew out of work initially done by Caltech faculty and graduate students; the collaboration between the campus and JPL continues to be very active and highly productive. Other off-campus facilities include the Palomar Observatory, with its 200-inch Hale Telescope; the Owens Valley Radio Observatory; the Big Bear Solar Observatory; and the William G. Kerckhoff Marine Biological Laboratory, all in California; and the W.M. Keck Observatory, which will house the world's largest optical telescope, and the Submillimeter Observatory, both on Mauna Kea, Hawaii.

Pictured above: Owens Valley Radio Observatory



Arnold Beckman and James McCullough in a Caltech laboratory, ca. 1933.

In 1934, chemist Arnold Beckman invented the pH meter, effectively launching a new era in the development of sophisticated scientific instrumentation. In the 1950s, John Roberts demonstrated the power of new instrumental techniques by using the first commercial nuclear magnetic resonance (NMR) spectrometer on a



Design for the acidimeter, later called the pH meter.

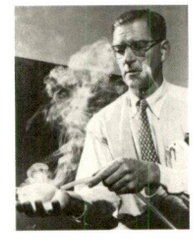
college campus to perform a series of experiments that altered our understanding of reactivity in organic molecules. The tradition of bringing new instruments to bear on scientific questions was continued in the 1970s by Leroy Hood and his group, who developed a prototype DNA synthesis machine that has become an essential tool in genetic engineering and biotechnology.

In 1989, Caltech dedicated the Beckman Institute, the largest building on campus. Work undertaken there will focus on the invention of instrumentation, methods, and materials that hold the promise of opening new avenues for fundamental research in chemistry, biology, and related sciences.

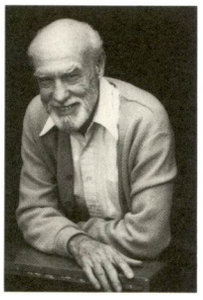


The Beckman Institute

At the end of the 1940s, Arie Haagen-Smit first identified the constituents of smog. His research opened the way for other Caltech researchers to elucidate the role of various emissions in the degradation of air quality. Later, geochemist Clair Patterson's demonstration that lead pollution from automobile exhaust had reached dangerously high levels was one of the factors in the federal government's decision to establish pollution controls within the auto industry. In the 1950s and early 1960s, Patterson's studies of the decay rate of lead isotopes were instrumental in determining that the earth has existed for 4.6 billion years.



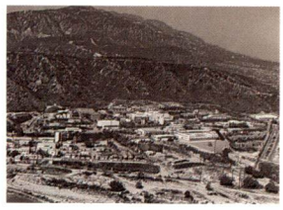
Arie Haagen-Smit



Roger Sperry

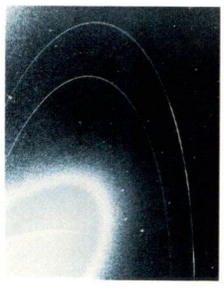
In the late 1960s and early 1970s, working at the forefront of the emerging discipline of neuroscience, Roger Sperry discovered that the left and right hemispheres of the brain are specialized for different capacities: the left for verbal thinking and language, the right for spatial-visual thought. Sperry was awarded the Nobel Prize in 1981. In 1986, under the leadership of chemist/biologist John Hopfield and computer scientist Carver Mead, Caltech established the first interdisciplinary doctoral program to study problems arising at the interface between neurobiology, electrical engineering, computer science, and physics.

Carver Mead also pioneered design techniques for VLSI (Very Large Scale Integration), techniques which proved to be powerful tools for the creation of complex electronic circuits on single semiconductor chips. Mead's work was a basis for revolutionary developments in electronic systems in the 1980s. In 1985, Charles Seitz and his students developed the Cosmic Cube, a revolutionary, message-passing multicomputer that signaled a new approach to high-speed computing and helped create a new segment of the computer industry.



Early days at the Jet Propulsion Laboratory.

In 1944, off-campus work by Caltech faculty and graduate students led to the establishment of the Jet Propulsion Laboratory, which later became the premier research and design center for the American unmanned space program, including flight missions to the moon and all the planets except Pluto. In 1989, Voyager 2 completed its grand tour of the outer planets, after being launched some 12 years before. Having flown by Jupiter, Saturn, and Uranus, the spacecraft sent back picture-postcard photos of Neptune—nearly 4 billion miles distant along



A view of Neptune's two rings, as recorded by Voyager 2.

NOBEL LAUREATES

1923 Robert A. Millikan*
Physics

1933 Thomas Hunt Morgan*
Physiology or Medicine

1936 Carl D. Anderson*
BS '27, PhD '30
Physics

1951 Edwin M. McMillan
BS '28, MS '29
Chemistry

1954 Linus C. Pauling*
PhD '25
Chemistry

1956 William B. Shockley
BS '32
Physics

1958 George W. Beadle*
Physiology or Medicine

1960 Donald A. Glaser
PhD '50
Physics

1961 Rudolf Mössbauer*
Physics

1962 Linus C. Pauling*
PhD '25
Peace

1964 Charles H. Townes
PhD '39
Physics

1965 Richard P. Feynman*
Physics

1969 Murray Gell-Mann*
Physics

1969 Max Delbrück
Physiology or Medicine

1975 Leo James Rainwater
BS '39
Physics

1975 Howard M. Temin
PhD '60
Physiology or Medicine

1976 William N. Lipscomb
PhD '46
Chemistry

1978 Robert W. Wilson
PhD '62
Physics

1981 Roger W. Sperry*
Physiology or Medicine

1982 Kenneth G. Wilson
PhD '61
Physics

1983 William A. Fowler*
PhD '36
Physics

CRAFOORD LAUREATES

1986 Gerald J. Wasserburg*
Geochemistry

**indicates those individuals who were members of the Caltech faculty when they received the award.*

NATIONAL MEDAL OF SCIENCE

1962 Theodore von Kármán*
1963 John R. Pierce*
BS '33, MS '34, PhD '36
1967 Alfred H. Sturtevant*
1969 Wolfgang K.H. Panofsky
PhD '42
1970 Allan Sandage
PhD '53
1970 Saul Winstein
PhD '38
1973 Arie J. Haagen-Smit*
1974 William A. Fowler*
PhD '36
1974 Linus C. Pauling*
PhD '25
1974 Kenneth S. Pitzer
BS '35
1975 Sterling B. Hendricks
PhD '26
1975 William H. Pickering*
BS '32, MS '33, PhD '36
1975 E. Bright Wilson, Jr.
PhD '33
1979 Richard P. Feynman*
1979 Simon Ramo
PhD '36
1979 Donald E. Knuth
PhD '63
1983 Seymour Benzer*
1983 Charles H. Townes
PhD '39
1986 Harry B. Gray*
1986 Hans W. Liepmann*
1986 H. Richard Crane
BS '30, PhD '34
1986 Bernard M. Oliver
MS '36, PhD '40
1988 George W. Housner*
MS '34, PhD '41
1989 Arnold O. Beckman
PhD '28
1989 Rudolph A. Marcus*
1989 Harden M. McConnell
PhD '51
1989 Eugene N. Parker
PhD '51
1989 Robert P. Sharp*
BS '34, MS '35
1989 Roger W. Sperry*

NATIONAL MEDAL OF TECHNOLOGY

1988 Arnold O. Beckman
PhD '28
1989 Alvin V. Tollestrup
PhD '50

**indicates those individuals who were members of the Caltech faculty when they received the award.*

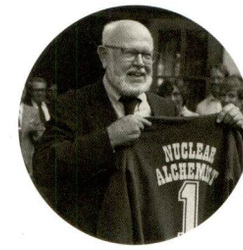
Voyager's route—revealing an extraordinary variety of terrains, some unlike any that had been seen elsewhere in the solar system.



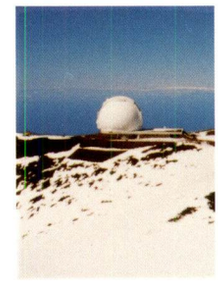
The 200-inch Hale Telescope at its dedication in 1948.

When Caltech astronomers put the 200-inch Hale Telescope on Palomar Mountain into operation in 1948, it was the largest and most powerful device in the world for viewing the heavens. Caltech faculty subsequently undertook such ambitious projects as the search for distant objects at the edge of the universe. In 1964, Maarten Schmidt determined that quasars—energy-emitting sources in deep space—are the brightest and most distant objects in the universe. His discovery provided a new vision of the universe at an early period of its history. In 1983, William Fowler was awarded the Nobel Prize for his studies of the nuclear reactions, deep within stars, that formed the chemical elements of the universe.

William Fowler, after winning the Nobel Prize.



In the coming decades, Caltech scientists will continue their work with the help of a new instrument, the W. M. Keck Telescope at Mauna Kea, Hawaii, the world's largest optical telescope. The partially completed telescope will see "first light" in 1990. When completed in 1991, it will have the capacity to look deeper into space—and hence further back in time—than has ever been possible before.

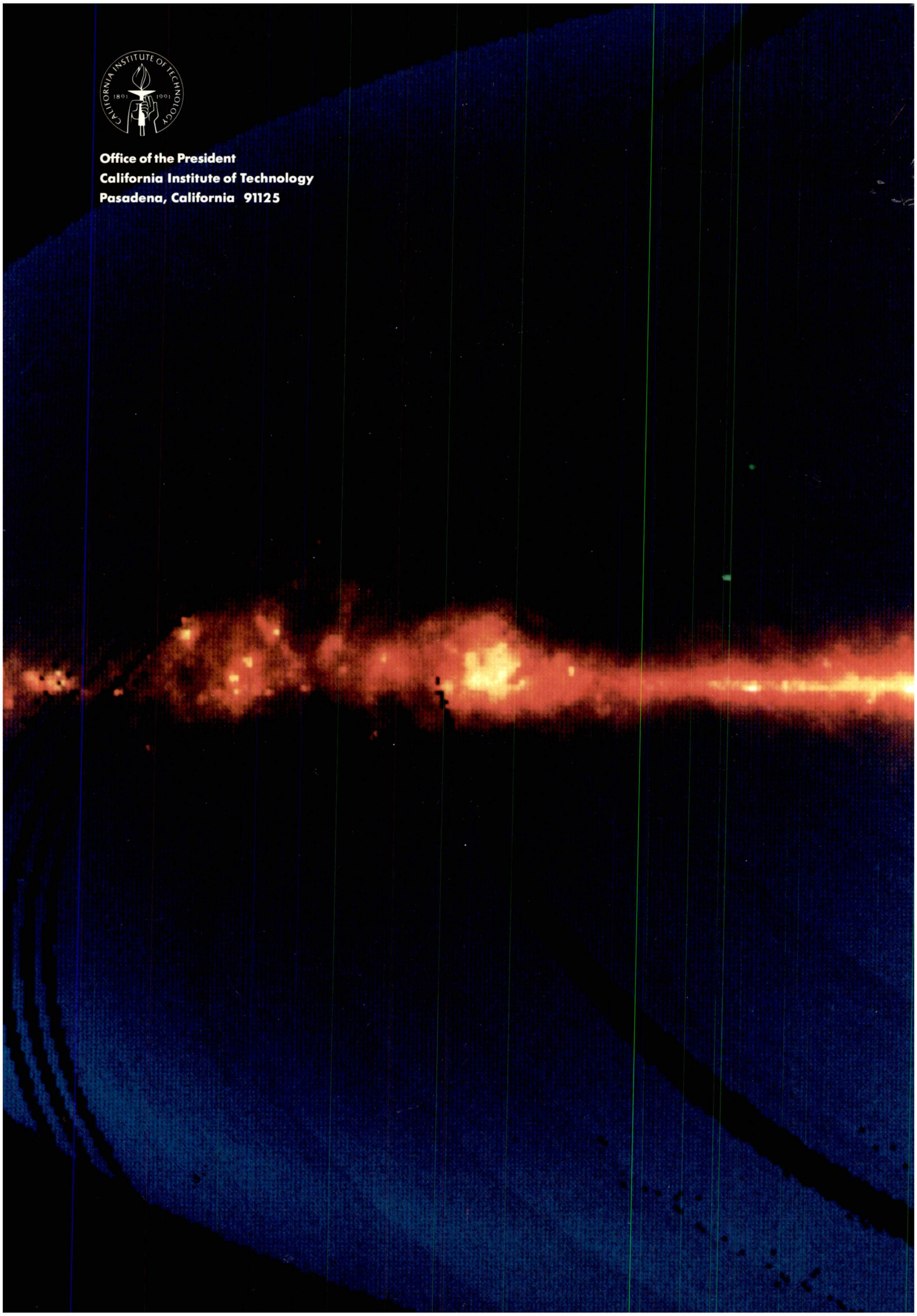


The W.M. Keck Observatory atop the extinct Mauna Kea volcano in Hawaii.

In times like these, there need to be a few places that look ahead and still dare to do the most ambitious things that human beings can accomplish. Caltech still has that ambition and that daring.

President Thomas E. Everhart

Inaugural Address
April 12, 1988



Office of the President
California Institute of Technology
Pasadena, California 91125