SCIENTIFIC AMERICAN

THE MECHANIZATION OF WORK

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September 1982

How Exxon's "energy
is saving millions of

Bill Lockett's guidelines set the targets for Exxon's refineries; creative engineering helps reach them.

Oil refining is the largest consumer of energy in the petroleum supply cycle. In fact, energy accounts for about half of a refinery's total operating costs. Recognizing this, Bill Lockett and his colleagues at Exxon Research and Engineering Company (ER&E) developed a unique system to measure and analyze energy efficiency in refineries—a system that helped Exxon save 30 million barrels of oil in 1981 alone.

Developing accurate, but broadly applicable standards for energy use was no easy task. Refineries by nature are extremely complex energy networks, with a wide variety of processes operating from temperatures below freezing to more than 2000°F, and from deep vacuum to 3000 + psi. These processes consume and release energy in many different forms. Furthermore, feedstocks, product slates, and refining intensity vary frequently.

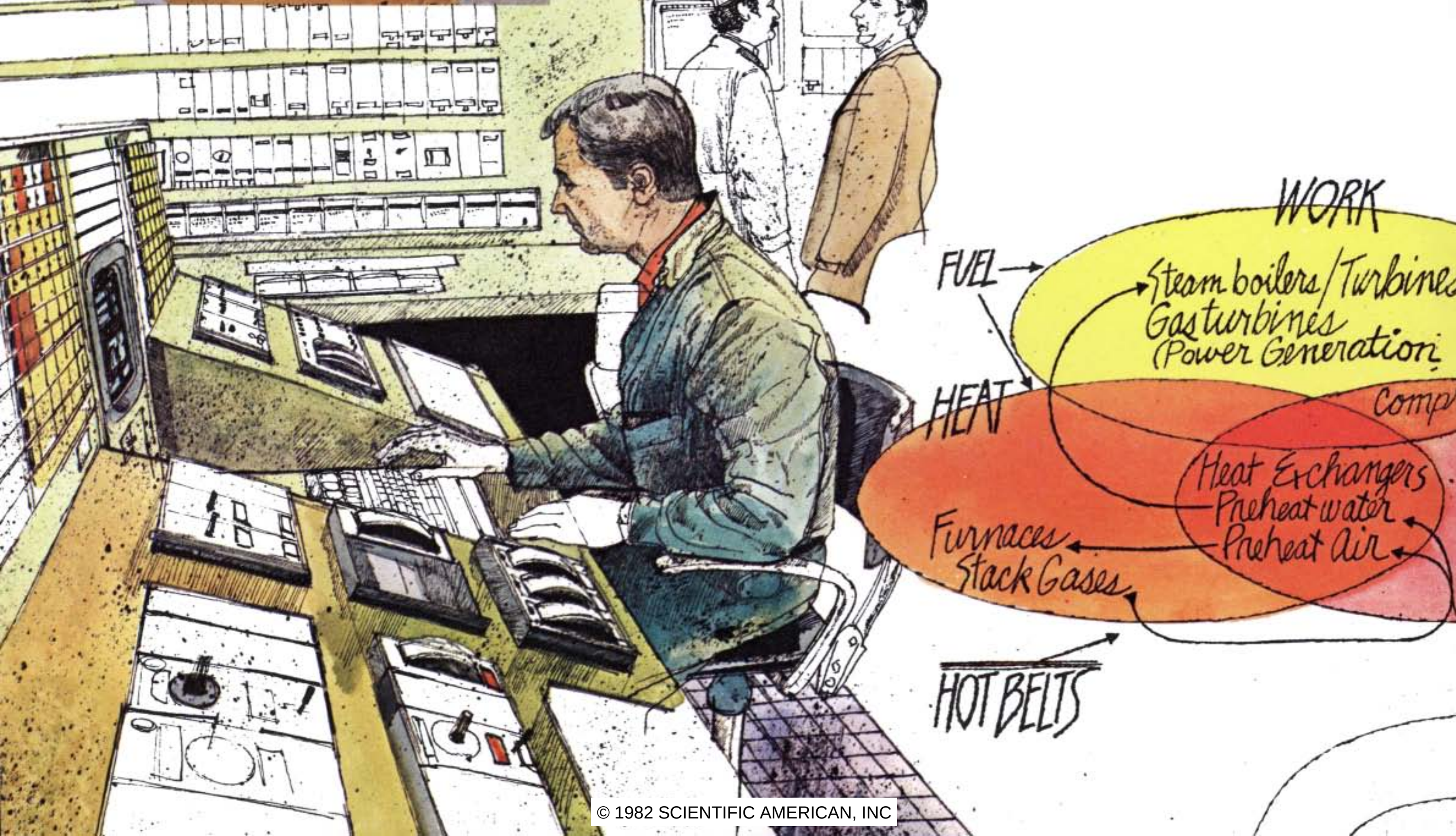
The Energy Guideline Factor System

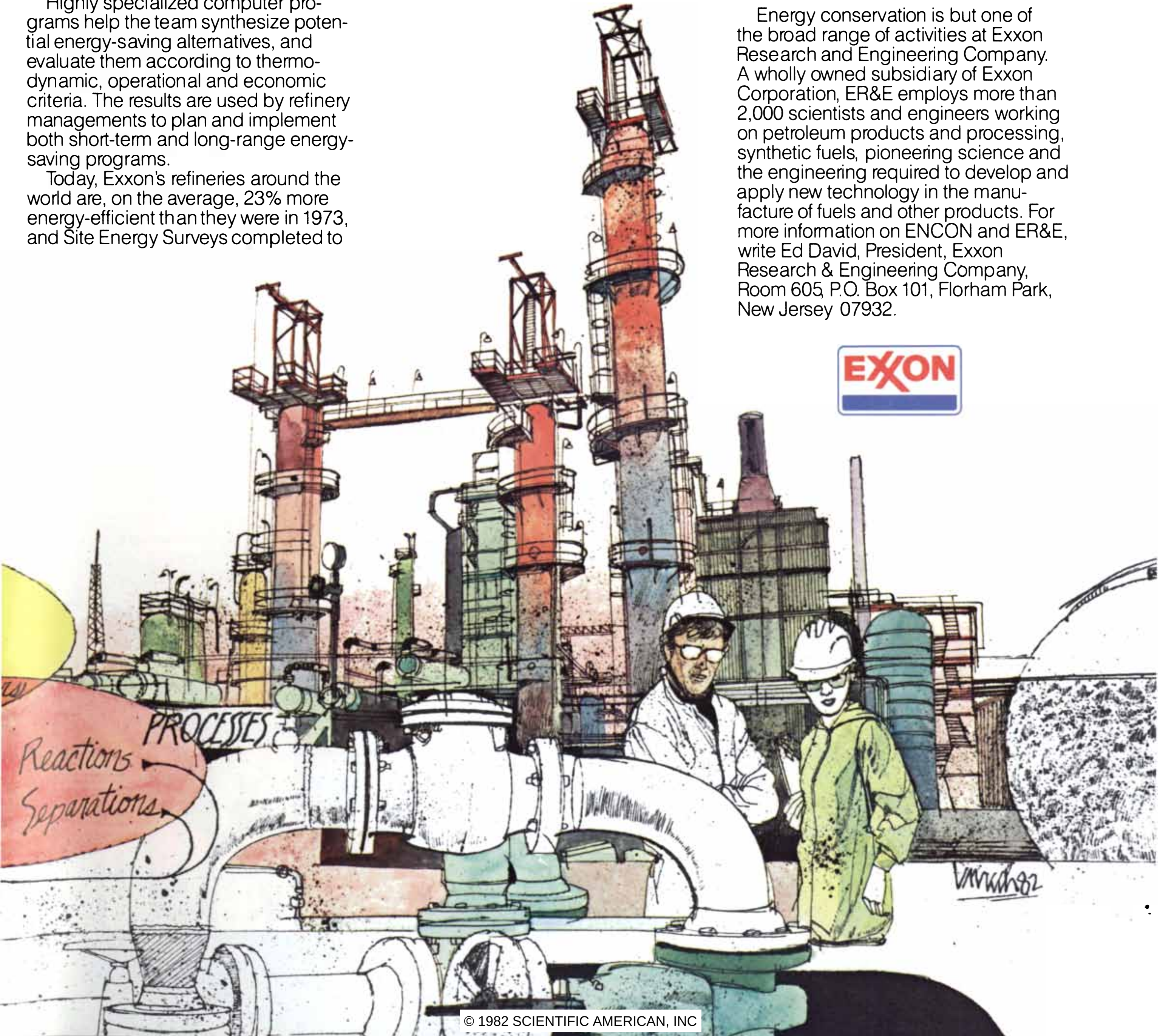
Several approaches had been tried in the early 1970's, before the ER&E team led by Lockett devised Energy Guideline Factors (EGFs) to provide the basis for comparing actual plant performance to an energy-efficient plant doing the same job. EGFs were developed for each type of refinery unit, such as distillation towers, desulfurizers, or catalytic crackers. The factors take into account such variables as feedstock quality, processing intensity and throughput. Refinery engineers anywhere in the world can evaluate actual performance of their process units against these standards and can combine individual guideline factors into a customized energy-consumption yardstick for an entire refinery.

The EGF system has proved to be a real success. It is used in all of Exxon's refineries around the world and has been licensed to twenty-seven other oil companies as well.

The Site Energy Survey

Another major element in Exxon's Energy Conservation (ENCON) program is an on-site survey to identify the most promising opportunities for modifying refineries to improve energy efficiency. Engineers from ER&E work as a

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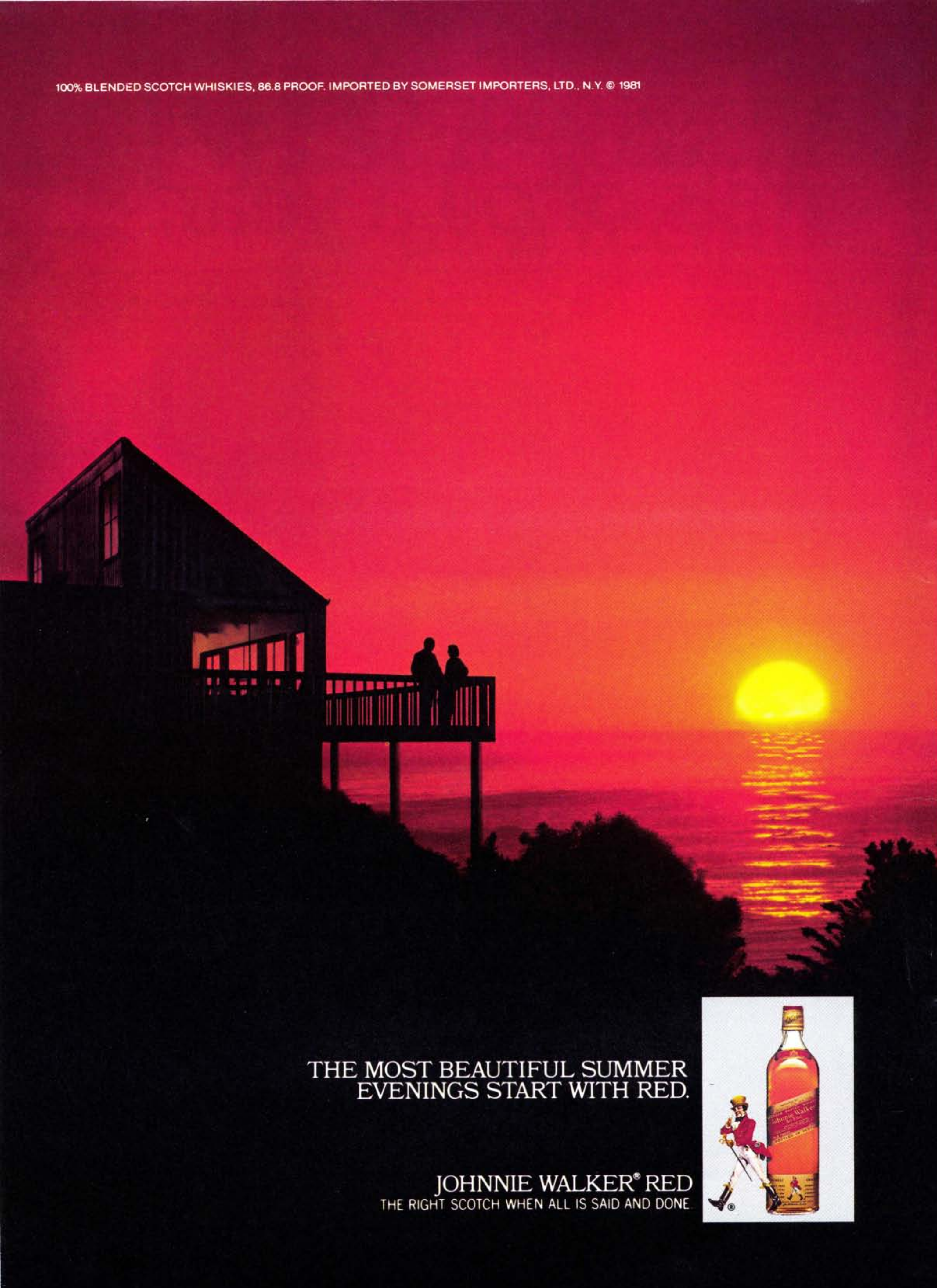
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THE COVER

The painting on the cover symbolizes the theme of this issue of SCIENTIFIC AMERICAN: the introduction of new technologies in the workplace and the social and economic consequences of technological change. The keyboard shown is that of the CGC 7900 Color Graphics Computer, made by Chromatics, Inc., of Tucker, Ga. The lower part of the keyboard is much like that of an ordinary typewriter, but an additional bank of keys controls functions that are useful in creating graphic images with the aid of the computer. For example, the operator can press the key labeled "Create" and enter a series of commands for the construction of a geometric figure; pressing the "Redraw" key causes the specified figure to appear on the screen of a cathode-ray tube. The unlabeled, colored keys assign colors to areas of a drawing; the functions of the keys in the top row can be defined by the operator. At one time the typewriter was almost the only device that had an alphabetic keyboard, and it was used mainly by clerical workers. Now the keyboard and its associated display have a new importance as the primary means of communication between people and computers. Analysts at Arthur D. Little, Inc., predict that by 1990 between 40 and 50 percent of all American workers will make use of such electronic devices.

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What is a "Money Market Fund" ...and why does it pay such high yields?

FREE BOOKLET BELOW

How it works

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But unless you have at least $100,000 of idle cash to spare, forget about being a private lender in the money market. Because that's normally the minimum amount needed to buy a money market "instrument." So it's closed to private individuals, except the very rich.

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A money market fund operates on a simple principle: Pooling. It receives relatively small amounts of money from a large number of individuals and small businesses...pools that money...and lends it in the money market with the degree of care and expertise as would any other major lender. The interest earned is then passed along to the Fund's investors, or "shareholders," as dividends. Therefore, you as a shareholder have the advantage of earning "money market" yields.

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LETTERS

Sirs:

As a law professor I was very interested in Douglas Hofstadter's piece on reflexivity and self-reference in the law ["Metamagical Themas," by Douglas R. Hofstadter; SCIENTIFIC AMERICAN, June]. There are, as he says, many examples. Article V of the United States Constitution prohibits amendments denying states equal representation in the Senate. The Supreme Court of India went out of its way to create a reflexivity problem by deciding that the normal process of amending the Indian Constitution did not apply to their Bill of Rights, even though no explicit provision prohibiting such amendments existed.

These reflexivity problems are fascinating, but I do not see what they have to do with "general procedures of argument," as Hofstadter (quoting Howard Delong) suggests. They have everything to do with the meaning of rules, law and politics but not with procedures of argument. Let me explain how at least one law professor would approach these problems. Every reflexivity example has the same structure. There is a rule that has specific cases coming under the rule. One particular case, by coming under the rule, appears to undermine the rule itself. For example, assume that the Supreme Court must decide cases properly appealed to it but that no judge can sit on a case in which he is personally interested. A case arises involving the reduction of judges' salaries, which is arguably unconstitutional. If the judges decide the case, they violate the rule against deciding cases in which they are personally interested, but failure to decide violates the rule requiring them to decide cases. The same structure exists for rules about amendment of the document containing the amending provision. Assume that the Constitution can be amended by a two-thirds vote but that one of the provisions requires a 100 percent vote. An amendment is passed changing the unanimity rule. If the amendment is valid, the unanimity rule is undermined, but if the amendment is invalid, the procedures for amendment are incomplete.

What is presented in all these cases is a problem of meaning and a conflict between rival conclusions, not a logical conundrum. The ultimate decision may be hard or easy, but the issues are not difficult to conceptualize. My own conclusion is that the Supreme Court should hear the case involving its salary because we do not want Congress deciding such issues and that the amending power should not extend to the unanimity rule because this breaks the social contract. These are hard cases, but another example presented in Hofstadter's article is easy. It concerns a contract to pay the rhetoric teacher Protagoras when his pupil Euathlus wins his first case. The teacher sues the pupil for the payment, figuring that if he wins the suit he gets his money and if he loses the suit he collects under the contract. But on what possible ground could he win the case before the pupil had won a lawsuit? And how could the original contract, in referring to a victory by the pupil as the occasion for payment, include a victory in a frivolous lawsuit by the teacher?

What I am pointing out is that reflexivity presents problems of choice, sometimes difficult, sometimes trivial, but that is nothing new in the law. Most important legal problems involve choice without involving reflexivity. Do we prefer a right of privacy or freedom of the press? The deeper point concerns the interaction of law and artificial intelligence and perhaps interdisciplinary studies generally. Reflexivity is undoubtedly an important problem in philosophy for reasons I do not fully appreciate. If developments in artificial intelligence are to be useful in law, however, they must take into account what legal problems are all about. To a lawyer reflexivity is not a relevant category but choice is. Indeed, I suspect that reflexivity is just a diversion for Hofstadter. In an earlier article on analogy he dealt with the imaginative problem of defining the First Lady of Britain. He there grappled with the problem of deciding what is like something else, which is the way lawyers always proceed in making choices. How we make analogies determines how we make choices, and that is the essential nature of all judgment. If that is what artificial intelligence is all about, I very much want to hear more.

As for the question of whether there are immutable rules, the answer is: Of course there are, if that's what you want.

WILLIAM D. POPKIN

Professor of Law
School of Law
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Bloomington

Sirs:

Professor Popkin raises a very interesting point in his comment on my column about Peter Suber's game Nomic. His point is essentially twofold: (1) The fact that any legal system is inevitably chock-full of tangles arising from reflexivity is amusing, but rather than being themselves a deep aspect of law such tangles are a consequence of other deep aspects, the most significant of which is that (2) the crux of any legal system is the ability of people to distinguish between the incidental qualities and the essential qualities of various events and relations, which ability results finally in recognition of what a given item is, that is, which category the item belongs to. Popkin calls this "choice." In conclusion he suggests that to discover the principles by which people can "choose" is a critical task for artificial-intelligence workers to tackle.

I feel that neither Suber's reflexivity nor Popkin's choice is more central than the other in defining the nature of the law. In fact, they are intertwined. Suber stresses that people, in choosing which of two inconsistent aspects of a supposedly self-consistent system shall take precedence, often make their choice without explicit rules (since if the rules were spelled out, they would be susceptible to getting embroiled in a similar kind of tangle once again, only at a higher level of abstraction). "Law can disregard logical difficulties and ground a solution on pragmatic rules, social policies and legal doctrines," Suber writes. "The effectiveness of policy, or what Popkin calls 'choice,' in plowing under logical obstacles is not the answer to the question but the mystery to be explained."

Coming to grips with this contrast between explicit rules and implicit principles or guidelines is of great importance if one wants to characterize how flexible category recognition—"choice"—takes place, whether one is doing research in artificial intelligence, philosophizing about free will or attempting to characterize the nature of law. Popkin, in fact, is rather charitable toward artificial-intelligence research, suggesting that it may someday yield clues, if not the key, to the mystery of choice. I think he is right about this. He may have failed to realize, however, that in any attempt to make a machine capable of choice one runs headlong into the problem of inconsistencies, level collisions and reflexivity tangles, and for the following reason.

All recognition programs are invariably modeled on what we know about perception in various modalities such as hearing and sight. One thing we know for sure is that in any modality, perception consists of many layers of processing, from the most primitive or "syntactic" levels to the most abstract or "semantic" levels. The zeroing-in on the semantic category to which a given raw stimulus belongs is carried out not by a purely bottom-up (stimulus-driven) or purely top-down (category-driven) scheme but rather by a mixture of them, in which hypotheses at various levels trigger the creation of new hypotheses or undermine the existence of already existing hypotheses at other levels. This process of sprouting and pruning hypotheses is a highly parallel one, in which all the levels compete simultaneously for attention, like billboards or radio commercials or advertisements in the subway.

Yet out of this seemingly anarchic chaos comes an integrated decision in which the various levels gradually come to some kind of self-reinforcing agreement. If a firm decision is to emerge from such a swirl of conflicting claims, there must be some kind of mental-level scheduler, something that functions like Robert's Rules of Order, letting various levels have the floor, scheduling collective actions such as votes, overriding or tabling motions and so on. In fact, to the best of our knowledge, this is the heart of the perceptual process. But this is the very place where reflexivity tangles crop up with a vengeance!

Any perception program has various levels of "inner sanctum," that is, levels of untouchability of its data structures. (These structures include not only the current hypotheses but also deeper, more permanent aspects of the program itself, such as the ways it weights various pieces of evidence, the rules by which it sorts out conflicts, the priority rules of its scheduler, and—of course—the information about the untouchability of levels!) Now, for the ultimate in flexibility none of these levels should be *totally* untouchable (although that degree of flexibility may be unattainable), but obviously some levels should be less touchable than others. Therefore any recognition program must have at its core a tiered structure precisely like that of government (or that of the rules of a game of Nomic), in which there are levels that are "easily mutable," "moderately mutable," "almost immutable" and so on. The structure of a recognition program—a "choice" program—is seen to be inevitably riddled with reflexivity.

The point of all of this is that the very reflexivity issues Popkin considers to be merely amusing sideshows in the law are actually deeply embroiled in what he sees as the meat of the matter, namely the question of how category recognition—discerning the essence of something—works. For that reason I found Suber's game not merely amusing but philosophically provocative as well. In fact, I consider the intertwined study of reflexivity and recognition, using the fresh methods of the emerging discipline of cognitive science, to be of great interest and importance for the light it may shed on the ancient philosophical problems of mind, free will and identity—not to mention those of the philosophy of law.

DOUGLAS R. HOFSTADTER

Department of Computer Sciences
Indiana University
Bloomington

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Meeting Japan's Challenge

Ninth in a Series

HAS JAPANESE INNOVATION REPLACED GOOD OLD YANKEE INGENUITY?

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The fact is, the Japanese are graduating more engineers; they're doing more nationally-coordinated and funded engineering; and they're also upgrading their well-known ability to implement the designs of others with a quality accent.

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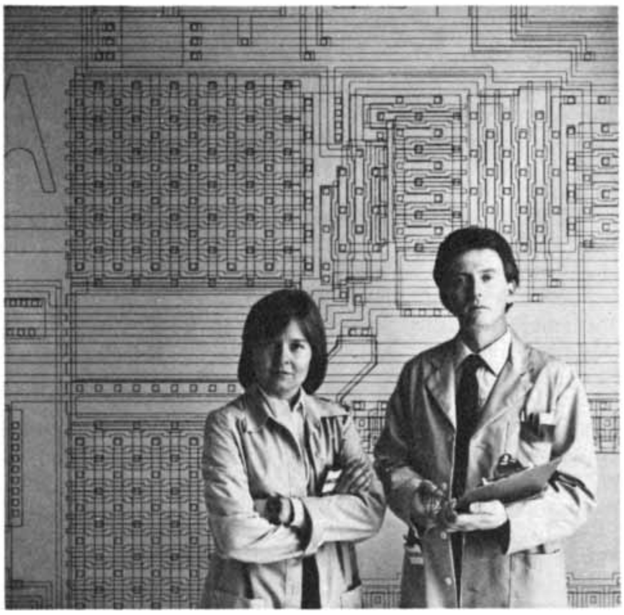
Most of these microprocessors and their computers were created by Americans.

Now the American semiconductor industry has given birth to the 16-bit microprocessor—a whole new generation that's up to ten times more complex and powerful than its predecessors. In fact, a 16-bit microprocessor has the capability of controlling an astounding 128,000,000 pieces of information.

These 16-bit microprocessors were developed and introduced by American manufacturers. Motorola's own version—MC68000—is widely acknowledged to have the most versatile computer architectural structure. You'll find it in new kinds of products never before economically practical: machines and instruments that talk, listen and respond; automatic production equipment that manufactures with higher precision and greater productivity; small home computers as powerful as large business computers built only five years ago.

And as innovative as these products are, new generations of microprocessors continue to open the realms of what's possible. For instance, we have announced a 32-bit version of the MC68000 that is the world's first fully upwardly compatible version of an earlier 16-bit sister machine. But that is not the point.

The point is that innovation and imagination in this field, as in others, is American. It is from this solid innovation base that we must meet Japan's challenge. As competition for world markets becomes more intense, it's this good old Yankee ingenuity that will keep us out front.



A single engineering drawing for the MC68000 covers an entire wall. Yet the actual microprocessor is only about 1/4 inch square.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1932: "New light has been shed on the already famous *Sinanthropus* discovery. Readers will remember that in 1926 and 1927, in a cave 37 miles from Peking, three human fossil teeth were discovered. In 1928 parts of some jaws and skulls came to light. In December, 1929, an almost complete skull of *Sinanthropus* was discovered in the same cave. Worked tools and the remains of hearth fires have now been discovered. 'Sandy Layer 4' has been found to contain an abundance of disintegrated charcoal from wood fires—old hearths like those so familiar to students of cave-dwelling man in Europe. The layer under Layer 4 is heavily impregnated with hearth-fire cinders. In the same layers the antlers of deer were found. They had been cut into lengths and used for flint-tool handles and as picks. The result of this discovery has been to accelerate the growth of an opinion previously held by some students of man's ancestry—that the beginning of human arts dates back to immense antiquity, before man had acquired his present form."

"W. S. Adams and Theodore Dunham, Jr., photographing the spectrum of Venus with the Mount Wilson 100-inch telescope, the great coudé spectroscope and the new red-sensitive plates, have found a group of sharp absorption bands in the infra-red, which they announce as being due to carbon dioxide. The identification of a familiar substance in a neighbor planet is always of great interest, and some have interpreted the new discovery as indicating the possible presence of life on Venus. This appears very doubtful. The atmospheric essentials for life such as we know it are oxygen and water vapor. No spectroscopic evidence of these has been found, nor do Adams and Dunham report it now. An atmosphere rich in carbon dioxide and devoid of oxygen seems far nearer what might be expected on a planet not generally different in composition from our own but on which life for one reason or another has never developed. It appears probable that the planets initially had no free oxygen in their atmosphere, although oxygen compounds such as H_2O and CO_2 may have been abundant, and that the oxygen now present on the earth has been liberated by the action of vegetation. If carbon dioxide is present in great abundance on Venus, this confirms rather than opposes the conclusion already drawn from the absence of lines of oxygen and water vapor. Our nearest neighbor among the planets bears every available evidence of being lifeless."

"The most important provision of the Merchant Airship Bill, which has passed through the House of Representatives, is the placing of the airship on the same footing as oceangoing steamers as far as compensation for carrying mail is concerned. The plans of the International Zeppelin Corporation call for placing four airships in service, two American and two German, and the construction of one complete terminal in the United States and one complete terminal in Europe. The airships designed for this service would be 858.8 feet long. The maximum diameter would be 132.9 feet, and the horsepower of the eight engines would total 4,800. The maximum speed would be 72.5 knots, or 83.5 miles per hour. There would be accommodations for 80 passengers with an exercising corridor of 400 feet, a central dining room, a smoking room, a lounge room, an observation car and so forth."

SCIENTIFIC AMERICAN

SEPTEMBER, 1882: "The International Electrical Congress held in Paris has decided to make use of the centimeter, gramme and second in all electrical measurements. They will retain the practical units, 'ohm' for resistance and 'volt' for electromotive force. The *intensity* of a current produced by one volt, with a resistance of one ohm, will be called an 'ampere,' and the quantity of electricity given by one ampere in one second will be called a 'coulomb'; the term 'farad' indicates the capacity of the condenser, which, laden with a volt, holds one coulomb. Dr. William Siemens has suggested adding to the list a unit of power. The power conveyed by a current of one ampere through the difference of potential of one volt is the unit consistent with the practical system. It might, Dr. Siemens suggests, be appropriately called the watt, in honor of that master mind in mechanical science."

"The cause of malarial diseases is said to have been discovered by Prof. Laveran, a French physician of Val-de-Grace. It is a very minute organism, named by him *Oscillaria malariae.* M. Richard, who announced the discovery in the French Academy of Sciences, has found these microbes in all the fever patients of the Philippeville Hospital in Algeria. They reside in the red blood corpuscles and completely destroy their contents. They can easily be rendered visible by treatment with acetic acid, but otherwise it is difficult to detect them in the corpuscles. They look like a necklace of black beads with one or more projections, which penetrate the cell of the corpuscle and oscillate or move like whips."

"The assumption that the earth was at one time in a fluid condition, as held by Laplace and by many astronomers and geologists, has been disputed with a suggestive presentation of evidence by Dr. Houghton before the Science Association at Montreal. Some of his reasons for doubting the fluidity of the earth or any other planet at any stage of its evolution are: 1. The possibility of the equilibrium of the rings of Saturn, on the supposition that they are either solid or liquid, has been more than doubted, and the most probable hypothesis concerning them is that they consist of swarms of discrete meteoric stones, discrete meaning that they are separate from one another in space. 2. The recent researches connecting the periodic showers of shooting stars with comets tend in the direction of showing that comets in cooling break up into discrete solid particles, and that probably the solar nebula cooled in a like manner. From these and other considerations it is allowable to suppose that the earth and the moon, when they separated from the solar nebula, did so in the form of solid meteoric stones, each of them having the temperature of interstellar space."

"The word energy was first used by Young in a scientific sense, and represents a conception of recent date, being an outcome of the labors of Carnot, Mayer, Joule, Grove, Clausius, Clerk Maxwell, Thomson, Stokes, Helmholtz, Rankine and other laborers, who have accomplished for the science regarding the forces in nature what we owe to Lavoisier, Dalton, Berzelius, Liebig and others as regards chemistry. In this short word energy we find all the efforts in nature, including electricity, heat, light, chemical action and dynamics, equally represented, forming, to use Dr. Tyndall's apt expression, many 'modes of motion.' It will readily be conceived that when we have established a fixed numerical relation between these different modes of motion, we know beforehand what is the utmost result we can possibly attain in converting one form of energy into another, and to what extent our apparatus for effecting the conversion falls short of realizing it."

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THOMAS G. GUNN ("The Mechanization of Design and Manufacturing") is managing director of the computer-integrated manufacturing group at Arthur D. Little, Inc. He got into his current work by an unorthodox route. He was an undergraduate first at Antioch College in 1960, dropping out to drive racing cars. As an antidote to automobile racing, his father persuaded him to join the Army, and he served four years before returning to college at Northeastern University. After earning his B.S. in mechanical engineering in 1970 he went on to get his M.B.A. from Dartmouth College in 1977. He joined Arthur D. Little in 1979 following brief tours of duty in management positions in the shoe and computer industries. Gunn's nonprofessional interests include flying and house renovation.

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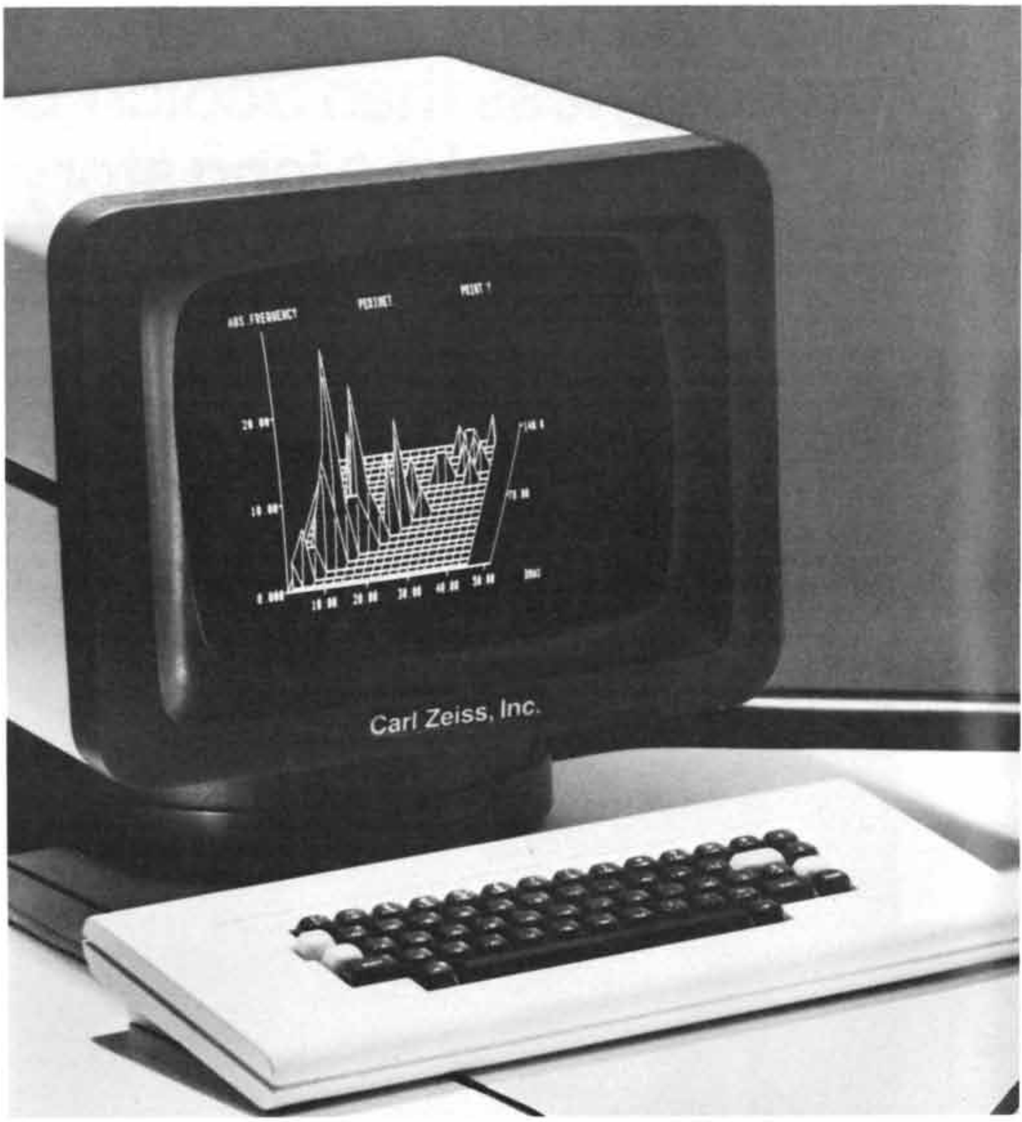

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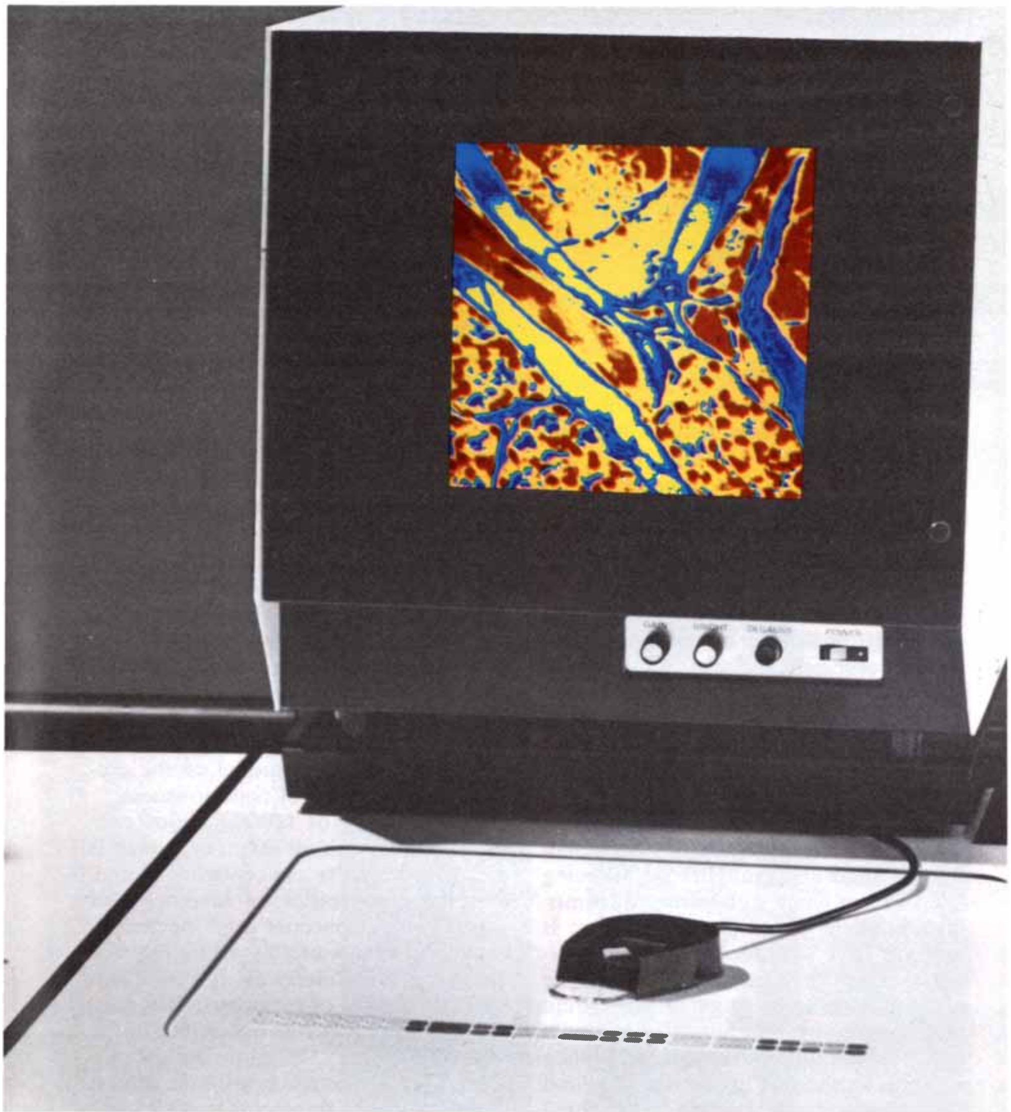

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Can inspiration be mechanized?

by Douglas R. Hofstadter

It is commonly held that there is such a thing as "the creative spark," that when a brilliant mind comes up with a new idea or work of art there has been "an unanalyzable leap of the imagination." Great creators are sometimes said to be a "quantum leap" away from ordinary mortals. People such as Mozart are held to be somehow divinely inspired, to have magical insights for which they could no more account than spiders could explain how they weave their wondrous webs. It is all felt to be a gift somehow too deep, too hidden, too occult to be in any sense mechanical. "You may mechanize your *logic,*" says the English professor to the computer scientist, "but you'll never lay a finger on *poetry.*" (You may substitute music or any other domain of artistic creation for poetry.)

Is this kind of statement irrational? Is it a reflection of a deep-seated fear that even this most sacred aspect of being human is doomed to be taken over soon by machines or silicon chips? Why make such a big deal out of an activity of the human mind that, like every other activity in life, has shades and degrees? After all, the creative blurs into the mundane so smoothly that it would seem hopeless to try to cull what is truly creative out of what is not. Or is there some clean dividing line that distinguishes the run-of-the-mill workaday deviser of ditties from the Great Composer of Eternal Symphonic Masterpieces? And if there is, is it possible that here lies the elusive difference between the living and the dead, the human being and the machine, the mental and the mechanical?

With such a "magical" view of creativity there is, of course, a problem. It would seem to imply that the poor composer of ditties is actually dead and mechanical inside, that only certified geniuses such as Mozart are qualitatively different from machines and that even Mozart was nonmechanical only when he was composing, certainly not when he was merely drinking beer at an inn. Probably most people who believe in the magical view of creativity would dispute this way of describing their position. They would maintain that Mozart was nonmechanical all the time and that moreover you and I, no less than Mozart, are also nonmechanical all the time. It is irrelevant that some, even many, human abilities have already been mechanized or will be mechanized someday.

About the touchy question of the mechanization of the mental many educated people believe that although a machine may now or someday be able to do a creditable job of acting like a person, any machine's performance will always remain lackluster and dull, and that after a while this dullness will always show through. You will simply have no doubt that the machine is unoriginal, that its ideas and thoughts are all being drawn from some storehouse of formulas and clichés, that ultimately there is nothing alive and dynamic—no *élan vital*—behind its façade. There may be nothing specific to point to other than the "vibes" you pick up of its dullness and unoriginality, but after a while they will inevitably start to come in loud and clear. (Incidentally, I would be delighted if some of the more vocal antimechanists felt that way, instead of insisting, as they more often do, that operational tests are of no value in deciding who or what possesses "genuine mental states.")

This sense that you will eventually be able to "just tell," from its inevitable lack of sparkle, that you are dealing with a machine and not a person seems to depend on a tacit assumption about human thought, one with which I fully agree, namely that the "creative spark" is not the exclusive property of a few rare individuals down through the centuries but rather is an intrinsic ingredient of the everyday mental activity of everyone, even the most ordinary people. In short, it seems that people who think machines—even intelligent machines—will always remain duller than people are tacitly relying on this thesis: Creativity is part of the fabric of all human thought, rather than some esoteric, rare, exceptional or fluky by-product of the ability to think, which surfaces every so often here and there.

With that thesis I agree. Where I differ with antimechanists is over the matter of whether creativity lies *beyond* intelligence. I see creativity and insight, for machines no less than for people, as being intimately bound up with intelligence, and so I cannot imagine a noncreative yet intelligent machine—something that, in order to make a point about what is essentially human, antimechanists seem willing to do. To me "noncreative intelligence" is a flat-out contradiction in terms.

In this column I should like to describe some ideas I have about how creativity is founded on mechanisms, mechanisms that to be sure lie deeply hidden in the depths of the structure of our brain but that nonetheless exist and can perhaps be approximated with the hardware and software of the machines we have today, crude though they are in certain ways. The gist of my notion is that having creativity is an automatic consequence of having the proper representation of *concepts* in a mind. It is not something you add on afterward. It is built into the way concepts are. To spell this out more concretely, if you have succeeded in making an accurate model of concepts, you have thereby also succeeded in making a model of the creative process, even of consciousness.

Another way of talking about concepts is to talk about memory, which is the "place" where concepts are stored. It is the organization of memory that defines what concepts are. Incidentally, when I first wrote the preceding sentence, it ended differently. It went: "It is the organization of memory that defines what concepts will be accessible under what conditions." On rereading the sentence I felt it was too weak that way. It took for granted the notion that all readers have a clear concept of what a concept is. But that is hardly to be taken for granted! Granted, we all have *some* concept of what a concept is, but do we have a *clear* one?

Therefore I dropped the phrase beginning with "will be accessible" and replaced it with "are." This way the sentence does more than simply state that memory is a storehouse of some things called concepts. It emphasizes that what establishes the "concepthood" of something is the way it is integrated into memory. Or conversely, nothing is a concept except by virtue of the way it is connected up with other things that are also concepts. In other words, the property of being a concept is a property of connectivity, a quality that comes from being embedded in a certain kind of network and from nowhere else. Put this way, concepts sound like structural or even topological properties of the vast tangly networks of sticky mental spaghetti.

That is more or less the image I think


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it is important to convey, namely that concepts derive all their power from their connectivity with one another. Having expressed the idea, I can now return to the sentence as it was originally put: "It is the organization of memory that defines what concepts will be accessible under what conditions"—and surely the happy choice of the right concept at the right time is the essence of the creative. Therefore it is imperative to study deeply the nature of that network, to ask the question: What is a concept?

Questions that quickly come to mind are: What is the relation between a Platonic, or general, concept, such as the concept of "tree," and the concept you form of some specific tree? That is, what is the distinction between semantic or perceptual *categories* and the representations of individual *instances* of such categories? How is a given situation filed away in memory so that one has access to it under an enormous variety of future situations—access that is often gained by analogy or other abstract pathways rather than by simplistic superficial traits? Or, to consider the other side of that coin, how does a given situation lead to the highly selective retrieval from memory of a small number of earlier situations that seem relevant? Only through a deep understanding of the organization of memory—which is to say, only by answering the question: What is a concept?—will it be possible to make models of the creative process. It will be a long and arduous process, not one that will yield answers soon, or even in a few decades. The right beginnings have nonetheless been made, in the sciences of cognitive psychology and artificial intelligence. Contributions will undoubtedly be made by philosophers of mind and neuroscientists as well.

A question that arises at the outset is: What kinds of objects have concepts stored inside them and what kinds do not? In Dean E. Wooldridge's book *Mechanical Man: The Physical Basis of Intelligent Life* (McGraw-Hill Book Company, 1968) there is a passage that opens the question wide:

"When the time comes for egg laying, the wasp *Sphex* builds a burrow for the purpose and seeks out a cricket which she stings in such a way as to paralyze but not kill it. She drags the cricket into the burrow, lays her eggs alongside, closes the burrow, then flies away, never to return. In due course, the eggs hatch and the wasp grubs feed off the paralyzed cricket, which has not decayed, having been kept in the wasp equivalent of a deepfreeze. To the human mind, such an elaborately organized and seemingly purposeful routine conveys a convincing flavor of logic and thoughtfulness—until more details are examined. For example, the wasp's routine is to bring the paralyzed cricket to the burrow, leave it on the threshold, go inside to see that all is well, emerge, and then drag the cricket in. If the cricket is moved a few inches away while the wasp is inside making her preliminary inspection, the wasp, on emerging from the burrow, will bring the cricket back to the threshold, but not inside, and will then repeat the preparatory procedure of entering the burrow to see that everything is all right. If again the cricket is removed a few inches while the wasp is inside, once again she will move the cricket up to the threshold and reenter the burrow for a final check. The wasp never thinks of pulling the cricket straight in. On one occasion this procedure was repeated forty times, always with the same result."

One might remark that it was not the wasp that was in a rut but the experimenter. Humor aside, this is a shocking revelation of the mechanical underpinning in a living creature of what looks like quite reflective behavior.

Something about the wasp's actions seems supremely unconscious, a quality totally opposite to what we human beings think *we* are all about, particularly when we talk about our own consciousness. I propose to call the *Sphex* wasp's quality "sphexishness" and its opposite "antisphexishness." I then propose that consciousness is simply the possession of antisphexishness to the highest possible degree. The point is that sphexishness and antisphexishness are two extremes along a continuum. Let me give a few examples distributed along that continuum, starting at the most sphexish and finishing with the most antisphexish:

1. A stuck record. This can be particularly disturbing if the recorded piece has a vibrant dynamism (such as the music of contemporary composer Steve Reich) the lifelike illusion of which is shattered by the mechanical repetition of the jumping needle.

2. The *Sphex* wasp herself and other examples from the insect world. For instance, suppose you have a mosquito in your bedroom. You try to swat it, and you miss. The mosquito takes off and flies around the room, losing you. After a while it alights and you spot it on the wall. Again you try to swat it and miss. As the cycle progresses is the mosquito aware of the repetition? Does the mosquito begin to sense that there is an organized effort to kill it or does each new swat come as fresh and as unexpected as the preceding one? Does the mosquito formulate some such notion as "the animate agent whose desire is to wipe me out"? Unfortunately for the mosquito but fortunately for you, it seems highly unlikely.

3. A herd of cattle in a corral, waiting to get branded. There is a general commotion and hubbub, originating with the noise each cow makes at the moment of branding and propagated outward by

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the cows closest to it. Does each cow in the corral recognize the overall pattern? Is each cow's increased state of agitation due to the fact that it perceives what is about to happen to it, or does it feel only a vague apprehension, perhaps a raised hormone level without any specific meaning or referential quality?

4. A dog that is fooled every time by a faking motion in which you pretend to throw a ball but do not release it. Actually I do not know any dog that would fall for such an elementary trick. I am, however, acquainted with a certain Airedale that did not catch on when I threw his toy onto an upstairs landing instead of down the hall where he expected it. I then led him up the stairs and showed him where it was. I expected he would know enough to go upstairs the next time. No such luck; he just ran down the hall again. Even after I had thrown his toy upstairs 15 times more, he *still* ran down the hall and then returned looking confused. Poor doggie! True, some of those 16 painful times he did start to go up the stairs, but each time he got only partway up, turned around and then hightailed it down the hall. To me it was a disappointingly sphexish kind of behavior for a dog.

5. Glassy-eyed gamblers in Las Vegas, glued to their slot machines. To this can be added glassy-eyed teen-agers and college students glued to video games and pinball machines. Is there not some kind of deadening rut here? And yet many people do such things over and over again with seeming pleasure.

6. A person who has the habit of singing or whistling in the midst of other activities and who, if you pay attention, can be heard to sing or whistle the same little refrain, day in, day out, year in, year out, never with any variety.

7. People who make what seems to be the same joke, only in slightly different guises, over and over again. Or inveterate punsters, who simply cannot stop making one pun after another.

8. Junior-high-school students who fill each other's yearbooks with the same pat phrases and corny poems *your* junior-high class did.

9. A mathematician who exploits a single technique in paper after paper, making advances in different branches of mathematics, yet always with a distinct, idiosyncratic touch and always, in some deep sense, doing just "the same old trick" again and again.

10. People whose behavior leads them down harmful pathways in their lives, for instance in their love affairs or their jobs. We all know people who "blow it" in the same way each time they are faced with a situation that matters.

11. Social trends that become completely stylized and predictable, such as the endless "sitcoms" television networks keep churning out and the movies one after another based on some gimmick exploited in slightly different ways. For instance, one could perceive the movies *Breaking Away, The Black Stallion* and *Chariots of Fire* as being simply three ways of plugging specific values for variables into one successful formula: an upcoming championship race, a lovable underdog, a rival and, of course, ultimate victory. And these works are sophisticated compared with some books and movies that far more blatantly exploit famous predecessors.

12. Styles in art that become dated and routinized to the point of no longer being creative. It happens to every style, but at the moment of its happening there are always some people who are breaking out of the rut and creating totally new styles. There are other people, however, who become technically proficient at an old style and continue to create in an old-fashioned vein.

How different are those last few examples from the stuck record or from the *Sphex* wasp? What is the real difference we feel as we progress down the list?

I would summarize it by saying that it is a general *sensitivity to patterns,* an ability to spot patterns of unanticipated types in unanticipated places at unanticipated times in unanticipated media. For instance, *you* just spotted an unanticipated pattern: four repetitions of a word. There was no explicit preparation for this act of perception in your genes or your schooling. All you had going for you is an ability to see sameness. All human beings have that readiness, that alertness, and this is what makes them so antisphexish. Whenever they get into some kind of "loop," they quickly sense it. Something happens in their head—a kind of "loop detector" fires. You can think of it as a "rut detector," a "sameness detector," but no matter how you put it the possession of this ability to break out of loops of all types seems the antithesis of the mechanical. Or, to put it the other way around, the essence of the mechanical seems to lie in its lack of novelty and its repetitiveness, in its being trapped in some kind of precisely delimited space. That is why the behavior of the wasp, the dog and even some human beings seems so mechanical.

How many computers do you know that react with outrage (or a guffaw) to the simultaneous occurrence on a single mailing list of "Bernie Weinreb," "Bernie W. Weinreb," "Mr. Bernie Weinreb, R.M.," "Barnie Weinrab" and so forth? Computers do not have automatic sensitivity to patterns in the data they deal with. To be sure, how could they be expected to? As the old saw goes, they do only what they are programmed to do. Computers are not inherently bored by adding long columns of numbers, even when all the numbers are the same. People are. What is the difference?

Clearly there is something lacking in the machine that allows it to have an unbounded tolerance for repetitive actions. The thing that is lacking can be described in a few words: it is the ability to watch oneself as one deals with the world, to perceive in one's own activities a pattern and to be able to do so at many levels of abstraction. Consider a hypothetical self-watching computer. To be sensitive in this way it should get bored whenever it is forced to add a long column of identical numbers together. Wouldn't you? It should get bored whenever it is forced to do just adding over and over again, even when the numbers are different. Wouldn't you? It should even get bored when it is asked to do many arithmetic operations in any kind of repetitive pattern. Wouldn't you? Any loop of any kind should become tedious. Shouldn't it?

But where does it stop? Surely if a computer could perceive that all it *ever* does is pull one instruction after another up from memory (a piece of hardware, not to be confused with human memory), execute the instructions and change various registers, it would yawn with boredom and probably soon go to sleep. By the same token you or I, if we ever gained access to the firings of our neurons, would find watching that activity to be one of the most stultifying things imaginable.

This, however, is not the kind of self-watching I mean. Watching one's own internal microscopic patterns of activity is bound to be boring, because any complex system is bound to be made up of thousands, millions or even more copies of small elements (gears, transistors, cells and so on). What is critical is to be able to watch activities on a completely different level: the collective level, in which huge patterns of activity of these many components assume regular kinds of behavior perceptible on their own. A hurricane is a huge pattern of activity of tiny atoms, but one with such regularity and pattern that we can predict the behavior of hurricanes without ever thinking of their constituent atoms. A *thought* is a huge pattern of activity of tiny cells, and much the same can be said of it.

Antisphexishness has to do with self-perception at this kind of level. Rather than watching its neurons or transistors or registers, an antisphexish being watches its own high-level patterns, looking for similarities in somewhat the way a meteorologist might look for one hurricane to follow the same general path as another.

Hence we should not expect or even want a self-watching computer to be able to see down to the level of its circuitry; it would not watch itself doing the machine-language operations of "add," "store" and "jump" in looplike patterns. The effects of such operations are to change the larger things in memory called data structures. Self-watching involves monitoring those changes as

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they happen, filtering out dull ones and recording certain aspects of the interesting ones in *other* data structures. (The fact that such recording would, on a more microscopic level, involve the very same kinds of elementary machine-language operations would be invisible to the computer, since the machine should be shielded from that detailed a view of itself.) Thus patterns in the changes taking place in *one* set of data structures would get recorded in another set of data structures. Should we then not set up a third level of data structures, a level to watch the second level for patterns occurring in it? And should we not also set up a fourth level to watch the third? This seems prime territory for an infinite regress: an endless hierarchy of structures, each one monitoring changes in the level below it.

Such is indeed the case, and it is because you are a self-watching human being that you caught onto the pattern, probably before I had spelled it out. It is in the nature of human pattern perception to be able to detect such infinite regresses and to stop them before they get anywhere. But what about the hypothetical self-watching computer, with its infinitely many layers of watchers?

Well, surely one of the most salient features—no, definitely the *most* salient feature—of what I have just described is the pattern of the data structures themselves: the hierarchy stretching upward repetitively toward infinity. Shouldn't this pattern be as blatant to a self-watcher as it is to us? It should indeed. If we were to label the bottom level 0 and the first watching level 1, then logically we should label the further levels 2, 3 and so on. Each level in this potentially infinite set can be identified with a natural number. Once the pattern is perceived by a watcher, that watcher can form the general concept of "all the levels seen at once," associated with the concept of "all the natural numbers conceived of at once." The conventional name for the set of all natural numbers is ω (omega), which can be taken as the name of a *new* watching level that looks out for patterns in this potentially infinite tower of watchers.

You need not worry, by the way, that in proposing such a self-watching computer I am presupposing an infinite machine. Precisely the opposite is the case. The entire reason for stopping infinite regress in its tracks is so that we will *not* need to build an infinite tower of data structures and watching processes, a feat that would clearly be impossible, aside from being monumentally sphexish. At any stage only a finite amount of recording would have been done, and so only a finite number—in fact a small number—of levels of structure would exist. The only requirement is that there be the *potential* to extend it further.

It would be the ω watcher that would perceive (as you and I and any other human being would) the infinite-regress pattern of attempts to build the ω tower itself. The ω watcher would catch any such infinite regress before it could start. If a change in Level 0 caused a change in Level 1 that caused a change in Level 2, and if these changes seemed to be patterned in such a way that an inevitable infinite ripple upward would ensue, the ω watcher, ever alert for such patterns in the other watchers, would come to the rescue, shouting "Wait! Enough! Halt!" Therefore no infinite regress would actually occur; it would be nipped in the bud by the same kind of mechanism that enables you to cut off a bore at a party. "Excuse me, I think I'll go get some more punch."

The problem is that there is nothing to prevent the ω level itself from going into loops, and so if we are going to prevent that, we must have a higher watcher: $\omega + 1$. Uh-oh! Before I even had a chance to begin spelling it out, you sniffed a new infinite regress. (You spoil all my fun!) Well, I am going to spell it out anyway. Level $\omega + 1$ needs to be watched by Level $\omega + 2$, and that level by Level $\omega + 3$. Thus we have a *second* potentially infinite tower of watchers, all of whom will be watched over by the Grand Watcher, Level 2ω. But if there can be *two* towers, why not *three?* And so, of course, it goes. Wheels within wheels, patterns of patterns of patterns. We get watchers 2ω, 3ω, and now our tower of towers needs a new Great-Grand Watcher: ω^2. And then—

Excuse me; I think I'll go get some more punch. There is a problem once you start getting into infinite regresses composed of other infinite regresses: the whole thing just never stops, and it becomes a *bore.* Well, not exactly a bore, but a complex and confusing thing whose reality and relevance become ever more questionable. And yet when you bring it back to the domain of sphexishness, it becomes the very real and very relevant question of how to build a machine that can sense unanticipated patterns in its own behavior.

This is related to a classic problem in the theory of computability: the halting problem. The problem is the question of whether there exists any computer program that can inspect other programs before they run and reliably predict whether or not they will go into infinite loops. (Going into an infinite loop means never coming to a halt, and conversely halting means avoiding any infinite loop.) The answer turns out to be no, and for elegant, deep reasons. Of course, the thing hinges on getting the halting inspector to try to predict its own behavior while it is looking at itself trying to predict its own behavior while it is looking at itself trying to predict its own behavior while— Excuse me; I think I'll go get some more punch.

The idea of the halting problem is closely related to the question about self-watching programs, but it is not really the same thing. First of all the halting problem is concerned with an inspection to be carried out on programs *before* they are running; it is like looking at blueprints of a building before it is built to see if it is earthquake-proof. Here we are talking about a program that is observing some program *while* it is running, and what is more, it is not just "some program" that it is watching, but *itself*. Of course, not *all* its attention is being devoted to seeing if it has got into a rut (since that would itself constitute ruttish behavior), but while it is doing other things it is keeping its eye peeled, so to speak, for signs of ruttishness within itself.

In computability theory, when a program or a system of any other kind turns back on itself in this way, the turning back on itself is known as diagonalization. To some people diagonalization seems a bizarre exercise in artificiality, a construction of a sort that would never arise in any realistic context. To others its flirtation with paradox is tantalizing and provocative, suggesting links to many deep aspects of the universe. Now here we see a *dynamic* diagonalization—a self-watching program—that seems to be closely connected with what makes a human being utterly different from a stuck record or a *Sphex* wasp. Surely that is not such a bizarrely artificial thing to ponder!

Probably the most significant difference between the halting problem and the idea of a self-watching program is that in trying to build an artificial intelligence we are not really so much concerned with the mathematical perfection of our self-watching system as we are with its likelihood of survival in a complex world. After all, that is what intelligence is about. Therefore if there is a mathematical theorem telling us that no program whatsoever will be a *perfect* self-watcher, able to catch itself in any conceivable kind of infinite regress, well, it is simply a statement that *perfect* intelligence is unreachable—something that ought to please us rather than dismay us, since it would be rather disappointing if someone came up with a finite program and could legitimately announce: "Well, folks, here it is at last, the end-all of intelligence, a *perfectly* intelligent program."

But don't worry about that. The metamathematical work of Kurt Gödel, Alan Turing, Stephen Kleene and others on such things as the halting problem and the theory of infinite ordinals (such as the towers of numbers and ω's) tells us that this scenario will never be realized, since there is neither a perfect halting inspector nor any ultimate scheme for naming ordinals. What this latter result means is that there is no finite mechanism that can possibly detect all patterns, patterns of patterns, patterns of patterns of patterns of patterns (aha!—I fooled you that last time, didn't I?), and so on.

In a famous paper titled "Minds, Machines, and Gödel" (in *Minds and Machines*, edited by Alan Ross Anderson, Prentice-Hall, 1964) the English philosopher J. R. Lucas attempted to capitalize on these types of "negative" results of metamathematics by asserting they provided the key element in a proof that no machine could ever be conscious in the way human beings are. Let Lucas speak for himself:

"At one's first and simplest attempts to philosophize, one becomes entangled in questions of whether when one knows something one knows that one knows it, and what, when one is thinking of oneself, is being thought about, and what is doing the thinking. After one has been puzzled and bruised by this problem for a long time one learns not to press these questions: the concept of a conscious being is implicitly realized to be different from that of an unconscious object. In saying that a conscious being knows something we are saying not only that he knows it, but that he knows that he knows it, and that he knows that he knows that he knows it, and so on, as long as we care to pose the question: there is, we recognize, an infinity here, but it is not an infinite regress in the bad sense, for it is the questions that peter out, as being pointless, rather than the answers. The questions are felt to be pointless because the concept contains within itself the idea of being able to go on answering such questions indefinitely. Although conscious beings have the power of going on, we do not wish to exhibit this simply as a succession of tasks they are able to perform, nor do we see the mind as an infinite sequence of selves and super-selves and super-super-selves. Rather, we insist that a conscious being is a unity, and though we talk about parts of the mind, we do so only as a metaphor, and will not allow it to be taken literally.

"The paradoxes of consciousness arise because a conscious being can be aware of itself, as well as of other things, and yet cannot really be construed as being divisible into parts. It means that a conscious being can deal with Gödelian questions in a way in which a machine cannot, because a conscious being can both consider itself and its performance and yet not be other than that which did the performance. A machine can be made in a manner of speaking to 'consider' its performance, but it cannot take this 'into account' without thereby becoming a different machine, namely the old machine with a 'new part' added. But it is inherent in our idea of a conscious mind that it can reflect upon itself and criticize its own performances, and no extra part is required to do

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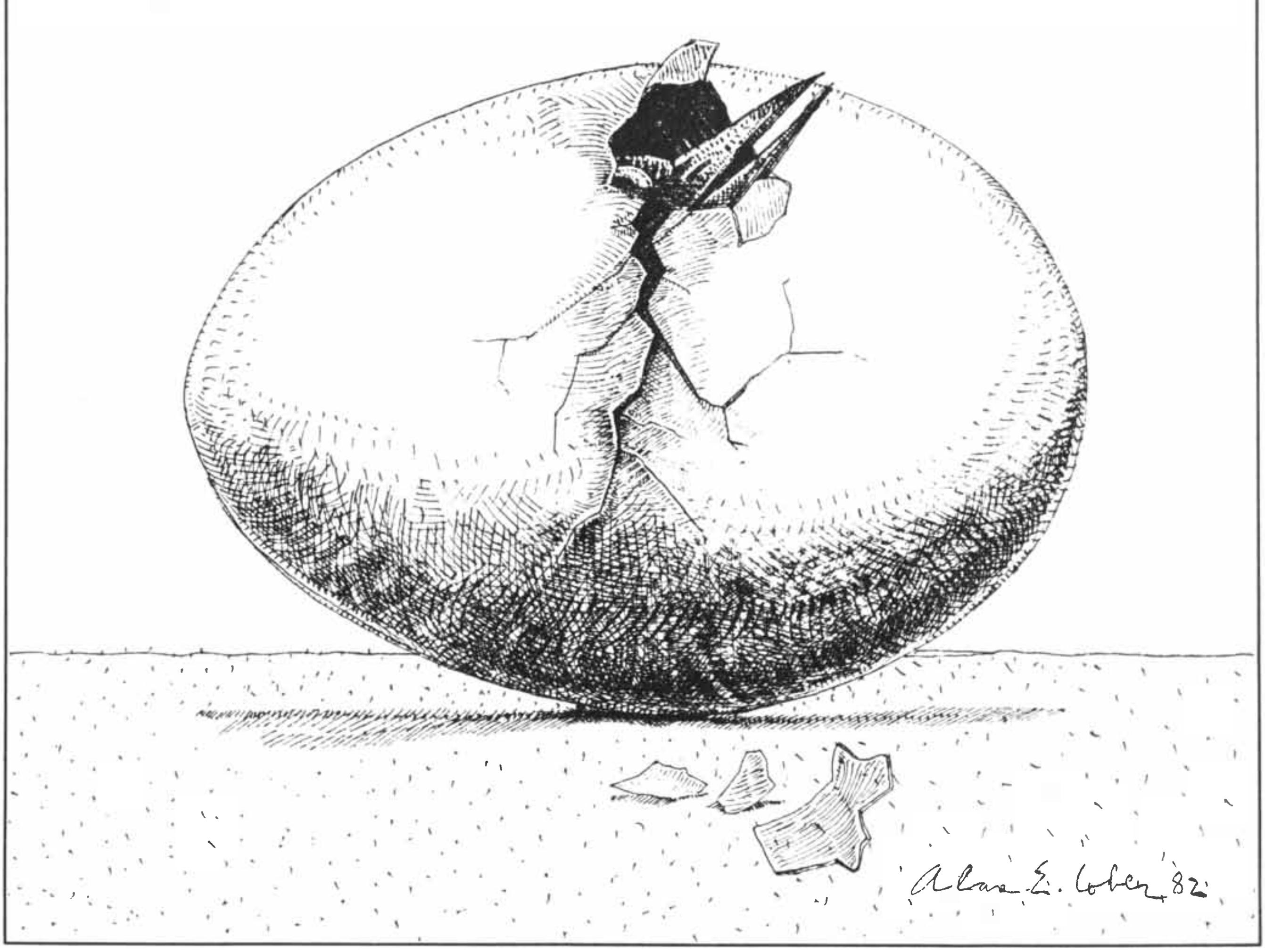

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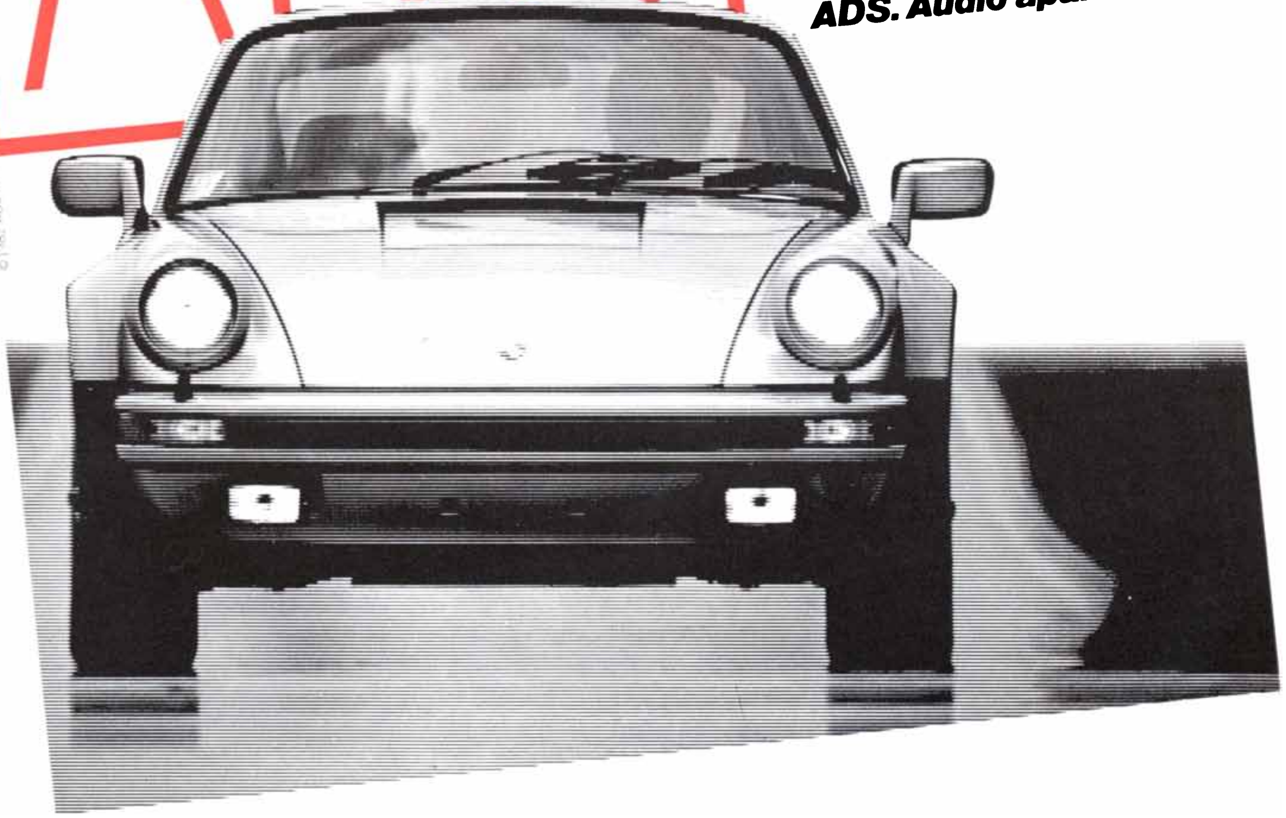

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this: it is already complete, and has no Achilles' heel."

Somehow—and I think understandably—Lucas was under the impression that human beings are endowed with powers equivalent to those of a self-watcher of infinite depth, someone who will detect and terminate any and all patterned behavior: the ultimate in antisphexishness. I call this hypothetical ability "breaking out of loops everywhere," or BOOLE for short (in honor of George Boole, who wrote *The Laws of Thought,* one of the most influential books of the 19th century).

Lucas seems to think that to be human is to be endowed with this BOOLE ability—this total and perfect antisphexishness—intrinsically. On reflection, however, one realizes that this cannot be the case. In spite of not being *Sphex* wasps or Airedales, we are all still vulnerable to getting caught in ruts, as I attempted to point out in the dozen-item list above. None of us is immune to it. Each of us—even the Mozarts among us—exhibits a "cognitive style" that in essence defines the ruts in which we are permanently caught.

Far from being a tragic flaw, this is what makes us interesting to one another. If we limit ourselves to thinking about music, for instance, each composer exhibits a "cognitive style" in that domain—a musical style. Do we take it as a sign of weakness that Mozart did not have the power to break out of his "Mozart rut" and anticipate the patterns of Chopin? And is it because Chopin lacked spark that he could not see his way to inventing the subtle harmonics of Maurice Ravel?

On the contrary. We celebrate individual styles, rather than seeing them negatively, as proofs of inner limits. What in fact is curious is that those people who are able to put on or take off styles in the manner of a chameleon seem to have no style of their own and are simply saloon performers, amusing imitators. We accord greatness to those people whose "limitations," if that is how you want to look at it, are the most apparent, the most blatant. If you are familiar with the style of Ravel, you can recognize his music any time. He is powerful *because* he is so recognizable, because he is trapped in that inimitable Ravel rut. Even if Mozart *had* jumped that far out of his Mozart system, he still would have been trapped inside the Ravel system.

The point is that Mozart, and you and I, are all highly antisphexish but not perfectly so, and it is at the fuzzy boundary where we can no longer quite maintain the self-watching to a high degree of reliability that our own individual styles, characters, begin to emerge to the world.

Although Lucas has been roundly criticized (I believe rightly) by many philosophers, logicians and computer scientists for failing to see many important subtleties of the Gödel argument on which he bases his paper, most of his critics have failed to see the crucial aspect of mind that Lucas was one of the first to point out. He correctly observes that the degree of nonmechanicalness one perceives in a conscious being is directly related to its ability to self-watch in ever more exquisite ways. Unfortunately too many artificial-intelligence people are ready to put down the Lucas article on the grounds that its central thesis—the impossibility of mechanizing mind—is wrong. What they miss is that it is pointing at deep issues having much to do with the very core of intelligence and creativity. The logician Emil Post wrote "The creative germ seems not to be capable of being purely presented but can be stated as consisting in constructing ever higher types. These are as transfinite ordinals, and the creative process consists in continually transcending them by seeing previously unseen laws that give a sequence of such numbers."

I stressed above the importance of the organization of memory and the pressing need to come at the question of what a concept is. Critical to the way our memory is organized is our automatic mode of storing and retrieving items, our knowledge of when we know and do not know, of how we know or why we do not know. Such aspects of "metaknowledge" are fluidly integrated into the way our concepts are meshed. They are not some kind of "extra layer" added on top by a second-generation programmer who decided that metaknowledge is a good thing, over and above knowledge! No, metaknowledge and knowledge are simmering together in a single stew, totally fused and flavoring each other richly. That makes self-watching an automatic consequence of how memory is structured. How is this wondrous stew of antisphexishness realized in the human brain?

And how can we create a program that, like a human brain, is all "of a piece," a program that is not simply a stack of ever higher "other-watchers" but is a genuine self-watcher, where all levels are collapsed into one? If we want to have a program that breaks out of the sphexish mold all programs seem to be in today, we have to figure out how a flexible perception program might exploit its own flexibility to look at itself. Of course, no such program will be written as I just stated. That is, it will not come into being in the following way:

Step 1. We write a flexible perception program.

Step 2. We turn that program back on itself as a self-watcher.

Rather, in order to achieve the results desired in Step 1 we must have incorporated the goals of Step 2 into the design from the start. In other words, the two goals are intertwined, more in the following sense:

Goal 1. Flexible perception.

Goal 2. Self-watching.

There is no chronological priority here, because the two goals are too intertwined for the one to precede the other. It is a tricky foldback, more elaborate than the one involved in the halting problem, yet in spirit related to it.

It is interesting that Lucas' article was based on Gödel's theorem, whose proof depends on making one of these seemingly impossible (or at least highly counterintuitive) foldbacks. In that proof a mathematical system of reasoning folds back on itself and subsumes itself as an object of study. What is fascinating in the proof is how in such a system there is a kind of level-collapse that ensues from the ability of a system to see itself. Rather than there being towers of watchers, then towers of those towers and so on ad infinitum in the worst possible kind of infinite regress, all those degrees and levels of self-perception are achieved at once by the fact that the system can mirror itself. Not that it mirrors itself in every aspect, mind you; that would entail contradiction. It does do so, however, at all levels of complexity.

The apparently distinct levels of watcher and watched are totally fused in the Gödel construction, exactly as Lucas would have them fusing in the minds of all conscious beings. The only thing Lucas failed to understand is that the ability to fold around and see oneself in the wonderfully circular Gödelian way does not—indeed cannot—bring with it *total* antisphexishness. That, fortunately or unfortunately, depending on your point of view, is a chimera.

Back in 1952 the philosopher and composer John Myhill wrote a lyrical article titled "Some Philosophical Implications of Mathematical Logic: Three Classes of Ideas" (*The Review of Metaphysics,* Vol. 6, No. 2, pages 165–198; December, 1952). The three classes are borrowed from mathematical logic, and Myhill's names for them are the "effective," the "constructive" and the "prospective." In logic they are known more technically as the "recursive," the "renotrec" (short for "recursively enumerable but not recursive") and the "productive." Their essence is described as follows.

A category is "effective" provided there is a way, given a candidate for membership in the category, of deciding without any doubt whether or not that object is a member. Is Ronald Reagan Chinese? Is the Pope Catholic? Although the two questions are easy to answer and would seem to imply that being Chinese and being Catholic are examples of the effective, they are slightly misleading. Was Bruce Lee Chinese? Is an excommunicated bishop Catholic? Examples such as these show that the

Set priorities

"Lydia, top priority today is making sure the plans for the new course get sent out. Then let's discuss..."

Dictate letters

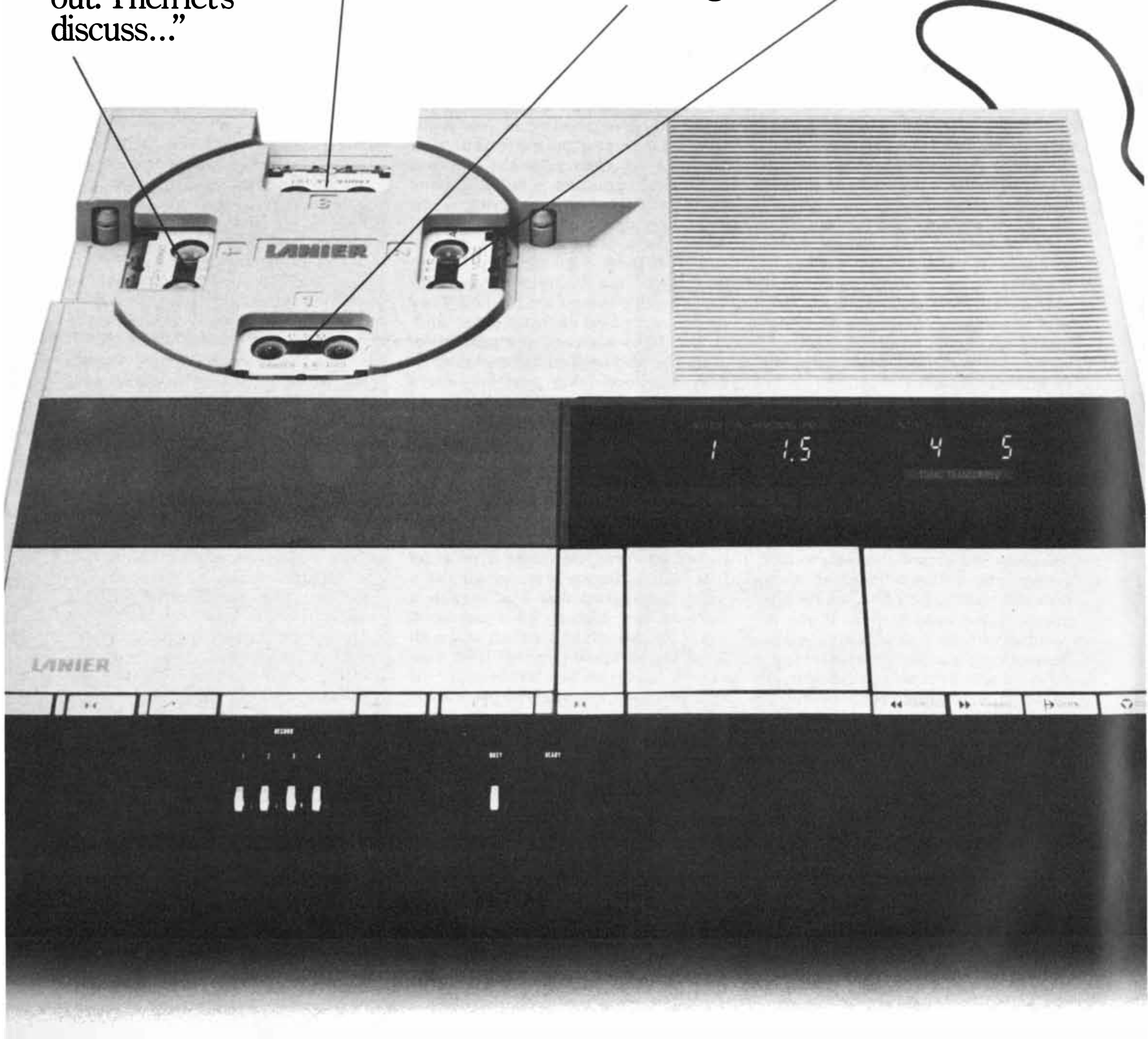
"A letter to the law firm: Dear Warren, I've just reviewed the contracts you've drawn up and have only one question..."

Leave messages

"Please tell David to go ahead and finalize that meeting in Chicago..."

Record phone calls

"Jack, I'm recording this call so I won't miss any details of your idea. It sounds like a winner."



—Arnold Palmer

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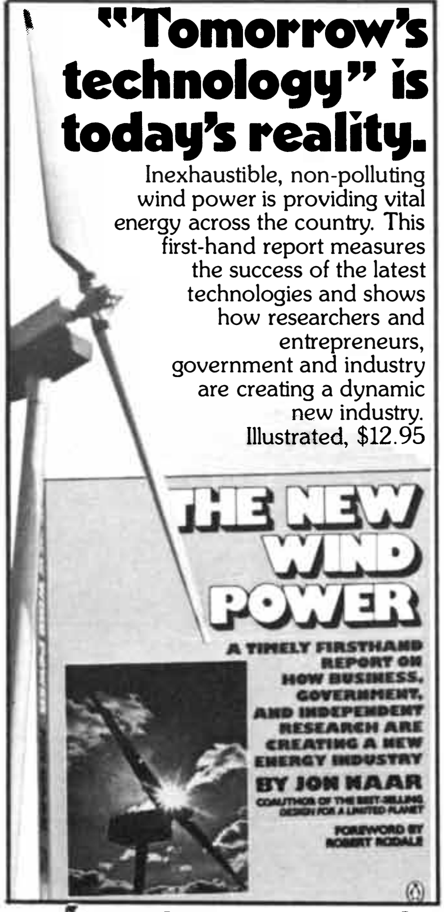

categories are not genuinely effective categories, but then nothing in the real world is as clean as it is in logic. I could have asked, "Is 29 prime?" but I wanted to show how these notions extend beyond the mathematical realm. In natural languages grammaticality (syntactic well-formedness) is a rather fuzzy property, but in an idealized language or formal system it would be a perfect example of an effective property.

We pass on to the "constructive." A property that is constructive is more elusive than one that is effective. The idea here is that there is some means whereby members of the category can be churned out one by one, and so you will eventually see any particular member if you wait long enough. At the same time there is no means for doing the complementary operation, namely churning out *non*-members one by one. Unfortunately, although this kind of set in mathematics is an extremely important one, easily definable examples of it are rather hard to come by. The set of all theorems in any formal axiomatic system is always recursively enumerable, but often its complement is too, which turns the set into an effective one rather than a constructive one. You have to be dealing with a formal system whose *non*-theorems are not themselves producible by some complementary formal system. Only then do you have a renotrec, or constructive, set. The set of theorems of any formalized version of number theory turns out (by Gödel's theorem) to have this property.

We finally come to the "prospective," also known as the "productive." Myhill's characterization of it is: "A prospective character is one which we cannot either recognize or create by a series of reasoned but in general unpredictable acts." Thus it is neither effective nor constructive. It eludes production by *any* finite set of rules. Nevertheless (and this is important), it can be *approximated* to a higher and higher degree of accuracy by a series of bigger and better sets of generative rules. Such rules tell you (or a machine) how to churn out members of this "prospective" category. In mathematical logic, work by Alfred Tarski and Gödel establishes that truth has this open-ended, prospective character. This means that you can produce all kinds of examples of truth—unlimitedly many—but that no set of rules is ever sufficient to characterize them all. The prospective character eludes capture in any finite net.

As Myhill's prime example outside of mathematical logic of this quality he suggests beauty. As he puts it: "Not only can we not guarantee to recognize it [beauty] when we encounter it, but also there exists no formula or attitude, such as that in which the romantics believed, which can be counted upon, even in a hypothetical infinitely protracted lifetime, to create all the beauty that there is." Hence beauty admits of a succession of ever better approximations but is never fully attainable. Beauty and irrationality are often linked. Is it coincidental that the first example of such a notion of something approximatable but never attainable in a finite process is called an "irrational" number?

Myhill is bold enough to speculate as follows: "The analogue of Gödel's theorem for aesthetics would therefore be: there is no school of art which permits the production of all beauty and excludes the production of all ugliness." To each coin there are two sides, and the reverse of beauty is ugliness. By an ironic coincidence the set complementary to a productive (or prospective) set is called, in the jargon of mathematical logic, "creative." It must be admitted that it would take a stupendously brilliant, if perverse, kind of creativity to produce all possible ugly objects.

If we see the aim of art as being the production of all possible objects of beauty (which is doubtless an oversimplification, but let us adopt it nonetheless), then each artist contributes objects in a particular style. That style is a product of the artist's heredity and formation, and it becomes a hallmark. To the extent that he has an individual style any artist is sphexish: trapped within invisible, intangible boundaries of mental space. That is nothing to lament. Artists in groups form movements or schools or periods, and what limits one artist need not limit another. Therefore by the fact that its boundaries are wider a school is less sphexish—more conscious—than any of its members.

But even the collective movement of a school of art has its limits, shows its finitude, after a period of time. It starts to wind down, to lose fertility, to stagnate. A new school begins to form. What no individual can make out clearly is perhaps seen collectively, on the level of a society. Thus art progresses toward an ever wider vision of beauty—a "prospective" vision of beauty—by a series of repeated diagonalizations, that is, processes of recognizing ruts and breaking out of ruts. As I like to put it, this is the process of "jootsing" (jumping out of the system) to ever wider worlds. This endless jootsing is a process any single step of which *can* be formalized but whose totality (so says Gödel) *cannot* be formalized, either in a computer or in any finite brain or set of brains. Hence one need not fear that the mechanization of creativity, if ever it comes about, will mark the end of art. Quite the contrary: it is a day to look forward to, because on that day our eyes will open (as will those of computers, to be sure) onto entire new worlds of beauty. It will be a happy day when hand in hand with our new computer friends we take an unanalyzable leap out of the system and go get some more punch.

Advertisement

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Phil Watanabe, Molecular Biologist, Dow Chemical U.S.A.

Since the early 1930's, Dow has been doing toxicology studies to determine what effect chemicals have on human beings.

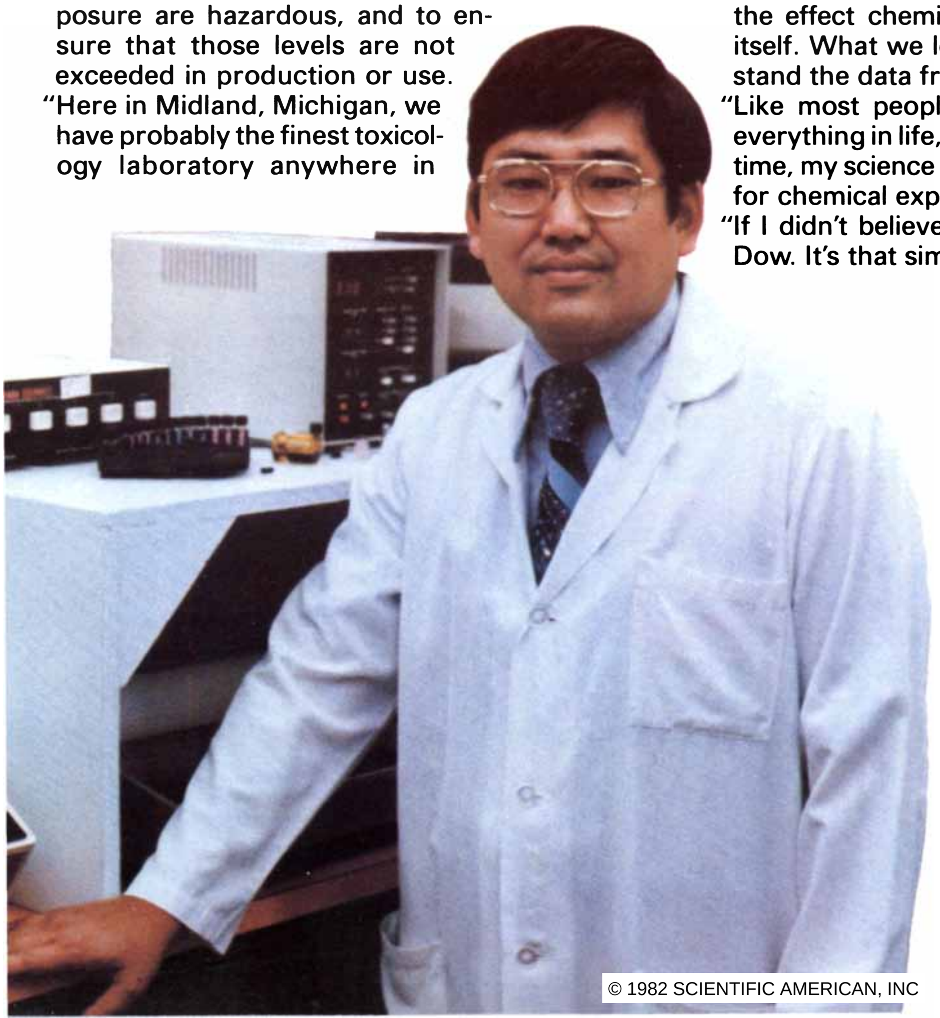
"People have a right to expect that," says Phil Watanabe. "That's why Dow has a total commitment to determine what levels of chemical exposure are hazardous, and to ensure that those levels are not exceeded in production or use.

"Here in Midland, Michigan, we have probably the finest toxicology laboratory anywhere in industry. Each of us tackles the problems of toxicity from a different angle. Laboratory animals are used in order to make realistic assessments of risk to human beings.

"Our science is more sophisticated than ten, fifteen years ago. My own work, for example, deals with the effect chemicals have on the DNA molecule itself. What we learn there helps us better understand the data from our animal studies.

"Like most people, I've learned there's a risk to everything in life, including chemicals. At the same time, my science tells me that acceptable risk levels for chemical exposure do exist.

"If I didn't believe that, I wouldn't be working for Dow. It's that simple."



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Michigan is a thoroughly integrated industrial state. Its principal industry is transportation. The infrastructure exists, however, to support virtually any other large- or small-scale enterprise.

The state's transportation or auto industry is not an isolated sector. It supports a gigantic infrastructure that booms when the business booms and suffers mightily when the industry stumbles. This complex ranges from the thousands of precision machine shops that specialize in machining of one or a few special parts to large machine makers whose computerized design and manufacturing (CAD/CAM) systems are every bit as sophisticated and advanced as those of the auto companies themselves.

There are software houses, computer builders, tool makers, upholstery firms, chemical and catalyst manufacturers, steel companies, robot builders, independent testing laboratories, furniture makers and more. A resource for the auto industry, they are also a resource for one another and a solid, varied, broad and deep base of technology on which new enterprises may securely establish themselves.

"This industry is the largest user of high technology in the world," asserts Dr. W. Dale Compton, vice-president, Research, at Ford Motor Company. Not only is the industry a user but also an originator. "We are high tech in the highest sense of the word," says Dr. Compton at Ford's extensive research and engineering campus in Dearborn.

The industry remains the largest industrial factor in Michigan, indeed, in the nation, and will continue to do so. But as a sector of the national economy and Michigan's economy in particular, the domestic auto industry has passed a watershed. Like a spring stressed beyond its yield point, it will recover but never to the same shape it used to be.

A casual observer might well wonder how the fortunes of a single industry could so affect the total well-being of a territory as large as Michigan—the seventh most populous state with ten million people on 56,817 square miles of land. Statistics tell the story dryly. A pie chart illustrating manufacturing employment in the U.S. as a whole splits into seven segments ranging from 9 percent (primary metals) to 20 percent (nonelectrical machinery). The transportation slice is 15 percent. For Michigan, the transportation slice is fully 43 percent.

A special section on Michigan advanced technology written by Peter J. Brennan and Development Counsellors International, Ltd. with special assistance by Michael Conboy, Research Program Manager, University of Michigan, Industrial Development Div., Institute of Science & Technology

But the traveler to Michigan is far more impressed not with pie charts but plants. From Saginaw to Kalamazoo, the state is dotted with enormous automobile manufacturing plants that seemingly dwarf the towns they so clearly support. Where there are not automobile plants, there are suppliers, like steel mills, machine shops, tool and die makers, test laboratories and the like—much of the other 57 percent of that pie chart.

Michigan Overview...

Uniquely surrounded by the deep waters of Lakes Erie, Huron, Superior and Michigan, split into the Upper and Lower Peninsulas by the Straits of Mackinac, and connected by the world's longest suspension bridge between anchorages, Michigan is as at home on water as any oceanic island.

No Michigander is more than 100 miles from a deep water lake.

International ports at Detroit, Port Huron, Bay City and Muskegon give the state's producers ready outlets to the world through the St. Lawrence Seaway. Many smaller ports handle heavy loads of lake traffic and recreational boating, too.

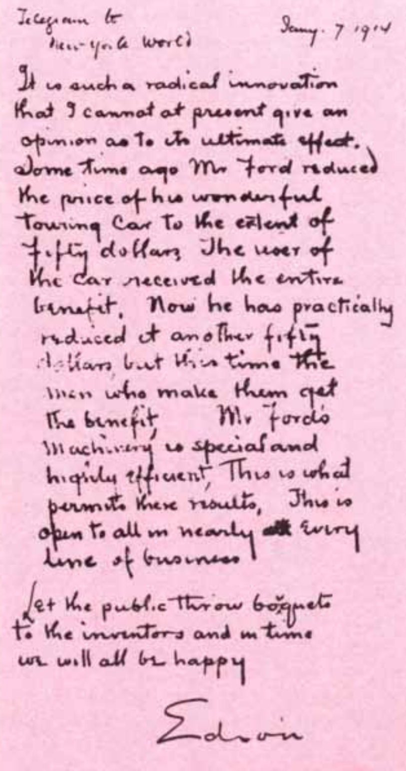
Michigan developed much like any other Midwest state through about 1900. Mining, quarrying, lumbering, farming and fishing formed the economic backbone and nurtured the mechanical industries that supported the natural resource sectors. Huge salt deposits under the state at Detroit and Midland gave rise to chemical industries. Herbert H. Dow discovered a way to produce bromine from the natural brines under Midland and founded the world's sixth-largest chemical company. Wyandotte Chemical Co. similarly prospered on electrochemicals produced from subterranean salt near Detroit.

It was an entirely new industry and new technology that gave Michigan its preeminence for so many generations. That same industry is ironically the cause of Michigan's current difficulties. Yet paradoxically, that industry is also the key to the recovery and the future health of the state's economy. The industry, of course, is transportation.

Tradition of Technology...

Toward the end of the 19th century, the automobile was the equivalent of today's small computer. There were hundreds of manufacturers. The technology was new. No city or region could then say it owned the automobile industry, though even then the industry was beginning to coalesce around Detroit under the banners of people like Ransom Olds, William C. Durant, founder of General Motors, and Henry Ford of Dearborn.

Henry Ford was a machinist. His genius lay in the ability to mechanize work and to increase productivity at such a rate that he could simultaneously earn a substantial profit, pay his workers the highest wages in the industry, constantly reduce prices to bring his cars within the reach of nearly everyone and continually invest in new plants and processes. Those automakers, indeed, any manufacturers, who survive and succeed to the present day followed that lead. Those who will sur-



Telegram to
New York World
Jany. 7 1914

It is such a radical innovation
that I cannot at present give an
opinion as to its ultimate effect.
Some time ago Mr Ford reduced
the price of his wonderful
Touring Car to the extent of
fifty dollars The user of
the car received the entire
benefit. Now he has practically
reduced it another fifty
dollars but this time the
men who make them get
the benefit. Mr Fords
Machinery is special and
highly efficient, This is what
permits these results, This is
open to all in nearly ~~all~~ every
line of business

Let the public throw boquets
to the inventors and in time
we will all be happy

Edison

Credit: Henry Ford Museum, The Edison Institute

Transcript for telegram from T.A. Edison dated Jan. 7, 1914 vive and prosper into the next century must continue to improve upon that lead.

The auto industry, as a user of technology as well as an innovator, drives other industries to do their best at the best possible price. The huge volumes make large markets. The complexity of the product—the vehicle—and its service place demands on components that will not be seen in other service. Integrated circuits, for example, lead a simple life in a home radio or computer, even in a short-lived military device. In the automotive environment, however, the life is much tougher.

Says Ford's Dr. Compton, "our specs on integrated circuits are tougher than military specifications." Technology extends in other directions, too—the catalytic converter for cleaning exhaust gases, for example. "We did with that device more in catalysis than the oil industry has ever done," says Compton with pride, referring to the petroleum industry's long experience with catalysts in its manufacturing processes.

"We have been overwhelmed in recent years with new technology," says Ford's Paul Guy, director of Engineering Research. "There is so much more available now than there was ten years ago. Research isn't our problem now, but how we can use what's available."

And the technology base grows larger, in perhaps unexpected directions, such as wind tunnels. General Motors has the only non-aerospace wind tunnel in the western hemisphere. Completed in 1981, the surrealistic machine can generate winds up to 150 mph for testing the aerodynamics of vehicle designs. Previously, the auto manufacturers had to depend on aerospace and Air Force facilities for such testing.

Detroit's older plant caused it to tag foreign competitors in technology as the latter built newer plants. But Detroit is catching up rapidly on manufacturing technology, appears far ahead on computer-aided design (CAD) technology, and may soon be ahead on computer-aided manufacturing (CAM) and testing (CAT). Existing data bases make the difference.

Says Dr. John W. Boyse, Senior Staff Research Engineer, Computer Science, at General Motors' sprawling, elegant Technical Center north of Detroit, "We're way ahead of anyone else because we have the data base and the tools to manipulate it." "We" means the U.S. auto industry and GM in particular and "anyone else" means, well, anyone else.

Larry C. Sugg, Chrysler's manager of Engineering Systems Development, agrees: "We have built a totally centralized on-line system that design, manufacturing and test people can all access equally." The Chrysler-developed system consists of four linked Control Data Cyber 700 computers driving 428 on-line terminals, of which 128 are graphics terminals. The common data base contains four billion bytes or characters.

Despite the large numbers of simultaneous users, the wholly random access system is astonishingly fast. And it's getting bigger. "We are adding fifty to sixty graphics terminals each year," says Sugg, "have four more Cybers on order and plan to get a Zector processor."

The system is hardly confined to automotive problems. National laboratories at both Livermore and Sandia have installed the same system to Chrysler's design.

Such huge data bases and the ability to manipulate them have great implications for the future of the auto industry. An automobile can go from conception to show room virtually untouched by human hands, and the better for it.

Says Chrysler's Larry Sugg, agreeing with his counterparts in the other companies, "The Japanese are ahead in computer aided manufacturing, but behind in computer aided design. They have backed into the system. We are coming in through the front end."

Ergonomics - Human Engineering...

For example, human engineering, or ergonomics, is essential to vehicle design. Traditionally, fitting people to cars has been done with dummies and cadavers, neither particularly lively. Chrysler developed a computerized three-dimensional mannikin, named Cyberman, which can assume any attitude in a computerized representation of a vehicle. Cyberman can assume either sex, any age, grow or shrink, get fat or thin at will. So useful is he, that Germany's Volkswagen bought him from Chrysler.

In another example of technology transfer, the Air Force Systems Command at Wright Patterson Air Force Base in Dayton, Ohio, bought a pre- and post-processor for structures analysis. "They came, they saw, they liked it," says Sugg with pride.

GM has a program it calls "GM Solid," a computer-based mathematical method for the generation and analysis of complex solids. Though GM has been using computer graphics for twenty years, as indeed have the other companies, the emphasis had been on analysis of sculptured surfaces. The system told you nothing about what went on beneath the surface. Says GM's Dr. Boyse, "We are interested in the part's properties as a solid, not as a surface." The program combines many simple solids, which can be analyzed into complex shapes that only the computer can analyze. The computer stores all the simple data to form the complex shape.

Many of the shapes now in the computer had no practical use by themselves and no one had done any work on them for years, not since complex solid geometry was an intellectual exercise in the 19th century. "We had to go back to 100-year old texts to find the mathematics for some of these shapes," remarks Dr. Boyse.

The result of all this is an enormous and accelerating saving in time, materials and money. The companies can integrate the entire process from design to manufacturing, developing the tooling, plant layout and even the machining steps as an integrated whole. The data base allows the manufacturer to store parts, including welding guns and fixtures, which the data base can meld with the part. As Chrysler's Larry Sugg puts it, "We can start ordering dies, tools, fixtures and the like long before we could previously."

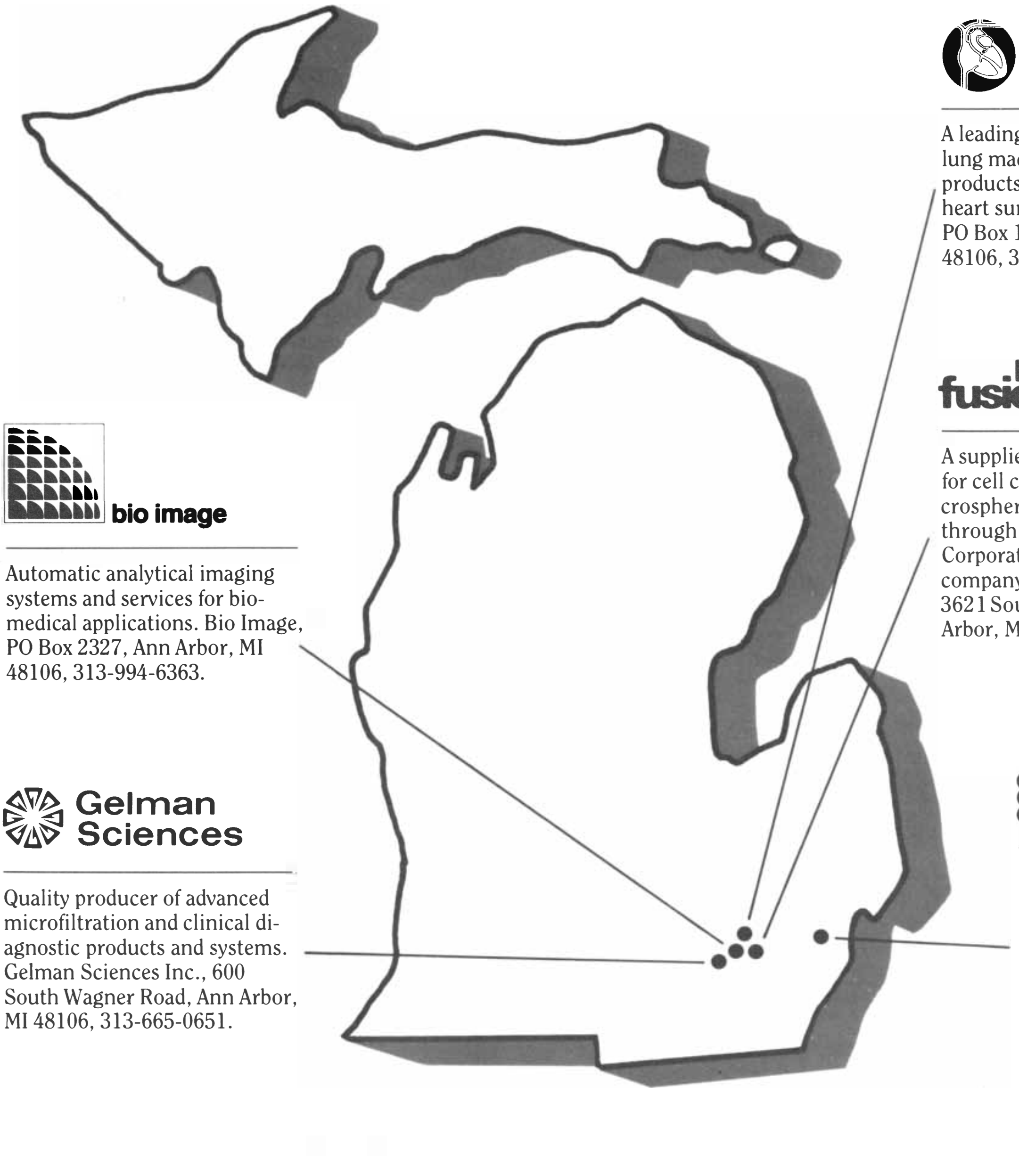
2,000 Machine Shops...

No manufacturer can operate without a ready source of precision-machined parts, sometimes in a quick emergency. "There are some 2,000 machine shops in the Detroit area alone," says James T. Graham, vice-president, Systems Engineering of Lamb Systems Group, "all specializing in something. If you need a machined part at two in the morning, you can get it."

Lamb is one of a number of major machine tool systems manufacturers that has grown up with the auto industry, and stands ready to supply any other large scale manufacturers. Scale is the key—these are far from back-alley tool shops. Their products are highly sophisticated transfer lines that combine a number of different machines to produce an entire assembly in a single continuous operation. A block of metal goes in one end, an engine comes out the other after being turned, milled, reamed, planed, bored, drilled, threaded, deburred and cleaned.

In large-volume systems like automotive plants, time is all important. "Our goal is to reduce parasitic time," says Dr. Thomas E. Evans, director of R&D for Lamb Technicon Corp., "which includes transfer, locating, clamping, tool advance and the like. The development has reduced it to 13.6 seconds from 17.4

Biomedical Industry says yes to Michigan



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The Biomedical Committee of the
MICHIGAN TECHNOLOGY COUNCIL

seconds. Our goal is 8.8 seconds. The Japanese, for all their manufacturing technology, still have a parasitic time of 17.4 seconds.

“What's it matter? We can increase our rate of part output to 409 parts per hour from 206,” explains Evans. “At 260 parts per hour, we equal the Japanese. At 409 parts per hour we will beat them.”

Transfer lines and materials handling systems are now being designed by Lamb and their competitors around electronic controls. That has increased flexibility and interchangeability of programs as well as a demand for programmers.

These tooling systems firms work closely with their customers to design tools and lines to fit specific manufacturing problems. The part and the tool are elements of the same system. CAD/CAM people at Lamb Technicon, for example, take a part submitted by a customer, then design the tool around it.

A typical analysis allowed a redesign of a transfer line designed with the traditional “educated guess” methods that increased stiffness over 200 percent while decreasing mass. These techniques shave many pounds from the weight of a vehicle before it is ever built.

Time-sharing CAD...

As CAD/CAM has come to the fore, time-sharing businesses have emerged to offer to smaller manufacturers all its benefits. Even the smallest machine shop or industrial enterprise anywhere in the country can have the top-level part and manufacturing design that Michigan manufacturers have at their doorsteps.

Not surprisingly, a major factor in this business is in Michigan. Manufacturing Data Systems Incorporated (MDSI) started in Ann Arbor, drawing upon the resources of the University community, to provide time sharing services to the manufacturing industries. The company links the manufacturing technology of Michigan to hundreds of firms across the country through its own communications centers in every state.

Schlumberger, the increasingly diversified oil service company that also owns Fairchild Semiconductors in California, bought MDSI in 1981 and in early 1982 acquired Aplicon of Burlington, Mass. MDSI now specializes in computer-aided manufacturing, while Aplicon's forte is computer aided design. They thus form a CAM/CAD team.

MDSI develops computer programming that allows any manufacturing engineer or technologist with a phone and terminal to specify while sitting at an interactive computer terminal the machining and tooling to develop the programming to carry it out. The heart of the system is a programming language called COMPACT II, easily learned by non-programmers and intended for people who know a lot more about machines than computers. The end result, step by step, is a program that will run a machine tool to produce the part that CAD has designed.

Of great value to manufacturers is a system called Group Technology. This is a computer-accessible data base that inventories existing forms and shapes. The automobile manufacturers have similar systems, but MDSI's covers a wider range. “It helps avoid re-inventing the wheel—almost literally,” says Henry Apfelbaum, director, Technical Planning, “With Group Technology, we can discover similar parts and similar manufacturing processes and save lots of time in laying out a factory floor. So far, in searching the data base, we find that 30 percent of items are similar and 15 percent are actually identical though they have different identifications.”

With Michigan's manufacturers leading the technological way, things are also changing at the actual manufacturing level. Motors and transmissions are replacing the hydraulic drives and actuators. Hydraulics gives great mechanical advantages over short distances, as well as precise control of acceleration and deceleration. But new designs of gears, particularly cycloidal drives and planetary systems, allow small electric motors to generate very high forces with precise motion and in more than the one axis to which hydraulic cylinders are limited. Further, as James T. Graham, vice-president, Systems Engineering of Lamb Systems Group points out, “Electromechanical systems don't leak hydraulic fluid. A factory can use 50,000 gallons of hydraulic fluid in a month. The lost fluid is a contaminant.”

Flexible Factory Automation...

“The automatic factory is here,” says Graham, pointing to the six-and-a-half-acre hydramatic transmission plant across the street. That plant has two and half miles of automatic conveyor tracking and receives a million items every day. People say “We gotta do it.!” “Hell,” says Graham forcefully, “we're doing it.”

Robots are doing it for factory automation, too. However, some people want to avoid the term “robot” and use such mouthfuls as “Flexible Factory Automation,” because they feel the popular conception of a robot is too limiting, too anthropomorphic. They believe the average person thinks of *Star Wars'* C3PO and R2D2—fully mobile, highly sentient, even sighted mechanisms that can fully replace humans in many functions.

There are many desirable things we might do and for which we have the technology if we want to spend the money. But we don't yet have the technology to produce independently programmed anthropomorphic robots like R2D2. Your average viewer would be quite disappointed at his first sight of today's usual industrial robot. The typical device is usually nothing more glamorous than a mechanical arm that picks something up from one place and sets it down in another.

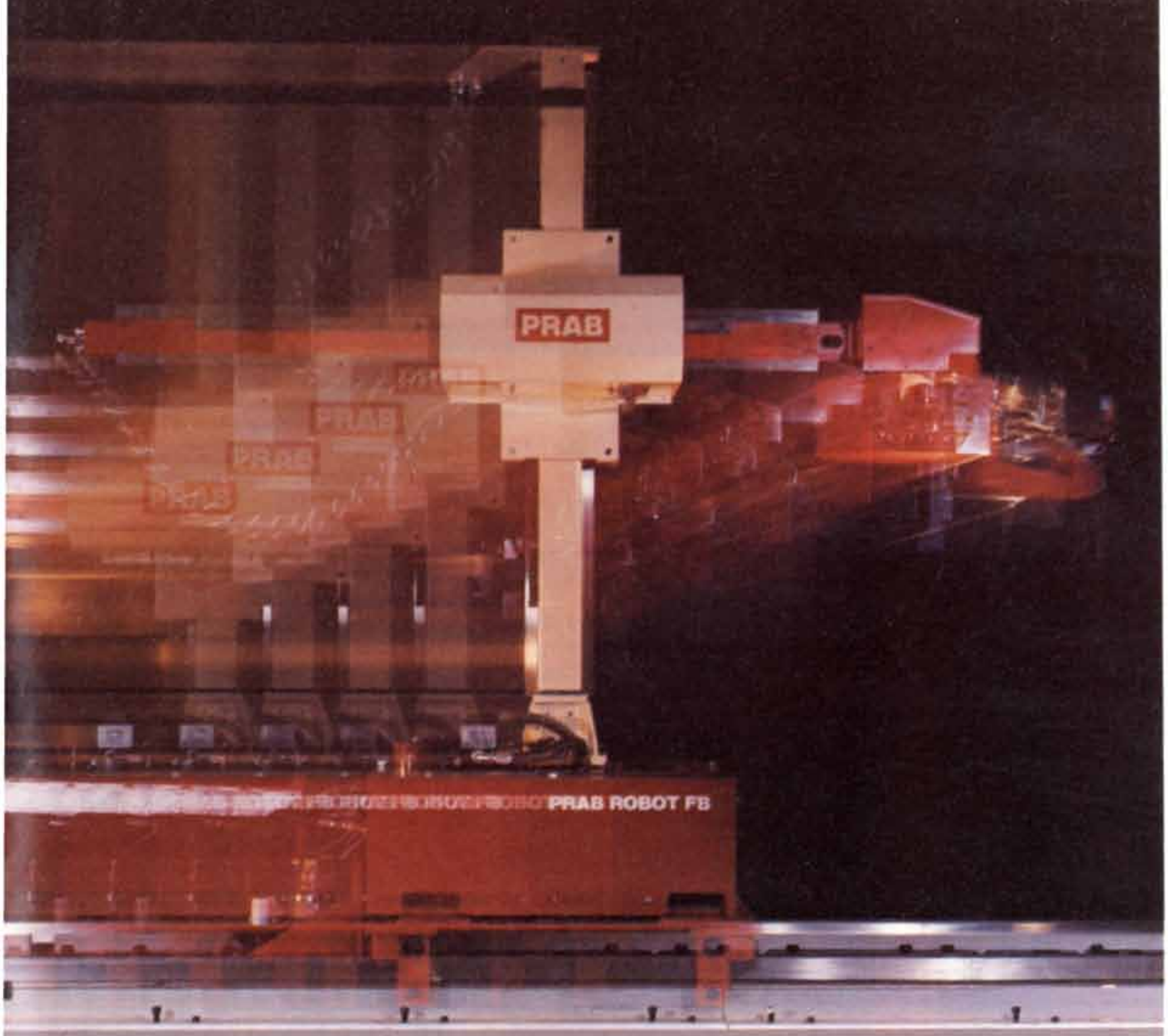
How complex the device and its control should be is all in the application. And those applications are turning up first in Michigan's transportation industry, in everything from small-parts handling to paint shops. The Detroit-based Robot Institute of America defines a robot as “A reprogrammable multi-functional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.” That could cover R2D2 as well as it can a simple pick-and-place device. And as with divinity for man, it is probably more than most robots or their makers aspire to.

“Limited Robots”...

Robots aren't even advanced technology, as Jack Wallace, President of Prab Robots in Kalamazoo, cheerfully admits. They are a triumph of engineering, an adroit marriage of linkages, gearings and bearings that brings the mechanical engineer to the fore in an age when the discipline has been eclipsed by the glamour of electronics.

But like so many useful devices, the robot is much greater than the sum of its parts. “A robot is a package of capabilities,” says Wallace, whose company in western Michigan built its first one in 1968 to solve one of its own manufacturing problems.

In one of Prab's operations, a conveyor dumped a part into a quench tank, another removed it and an operator lifted the piece from the second conveyor—hot, heavy, dull, repetitious work. The ideal job for an industrial robot. Wal-


PRAB
PRAB ROBOT FB

lace looked at what was then available "but that robot was overkill for the job," he recalls. "We needed a limited robot and built one with the right geometry. We built it to enhance our own business." There were no other buyers in those days.

Mr. Wallace does not get very philosophic about the advanced technology of robotics. "We designed our original robot to be maintained by existing plant maintenance mechanics," he says. Initially, simple electrical circuits—drums or cams driving microswitches—controlled the devices. "We continue to use those simple methods," says Wallace, "but now we also use programmable controllers."

"As a practical matter," says Wallace, "the flexibility of programming is in the selection of applications. Once a robot is set up for a particular task, it probably will not be moved to another one. Flexibility of choice in types of robot," he continues, "is more important than flexibility within the robot."

It is no accident that the robot societies are based in Detroit, nor that the state's universities have expanding programs in robotics, or that the recently established Industrial Technology Institute, set up to further flexible factory automation, is popularly called the Robotics Institute. It is even no accident that the Environmental Research Institute of Michigan (ERIM) at Ann Arbor has turned its talents in image recognition, honed on satellite surveys of the Earth, to developing the gift of sight for robots.

ERIM has developed a cytocomputer which can continuously process TV-type or gray-scale images in real time. This is a great advance over such primitive image recognitions systems as bar code or matched-shape recognition, or even the much more sophisticated binary recogntion in which the image either is or is not. With gray-scale sight a robot can pick items from a confusing background.

Many robotic environments do not require gray-scale discrimination. "But an auto plant," says Walt Cwycyshyn, supervisor of robot development at General Motors, "is a gray-scale environment."

GM is the nation's largest single user of robots, with some 1,700 on duty. Cwycyshyn and program director Ralph W. Behler maintain the company's robotics laboratory at the Technical Center, started in 1973–74. Last year some 6,000 people visited the facility, which GM uses to evaluate and test vendors' designs and to try out new applications.

A visit to the lab is a trifle unnerving and fascinating, not unlike watching monkeys in the zoo. Though one could hardly mistake the angular forms for monkeys or men, the complex motions they perform seemingly of their own volition are mesmerizing. There are great giants that toss about entire engines or bodies. Dainty midgets delicate as flamingoes pick and place nuts and bolts. And a quartet of exotic birds locked in a ritualized mating dance, hand bits and pieces to one another, stand aside, move forward and back in minutely choreographed, precisely detailed motion. Where there is only the clatter of machinery, the mind hears exquisite music.

Technology Development...

Recognizing that the future belongs to advanced technology, Governor William G. Milliken, marshaled the wise men of the state. The response from leaders in every sector was immediate, concerned, enthusiastic and, above all, participating. These were not superannuated semiretirees lending once-prestigious names, and only that, to handwringing committees. Rather, they were working and busy executives wholly involved in going enterprises and as concerned with the future course of their state as the Governor.

The lead development group is the Governor's High Technology Task Force. Formed with such people as Herbert D. Doan, former president of Dow Chemical Corp. and now head of Doan Resources, a Midland venture capital firm, the Task Force has worked closely with existing organizations. These include the State's own Office of Economic Development, the various Chambers of Commerce, the Industrial Development Division in the Institute of Science and Technology at the University of Michigan, the Michigan Council of Professional, Scientific and Technical Associations, and the state's colleges and universities.

The degree of cooperation and coordination has been remarkable. The experience bodes well for the future intersectoral coordination that will be needed to make plans and proposals into programs and plants.

The Governor's Task Force concluded there were two areas of realistic opportunity that the state could exploit. One is the factory of the future—"flexible factory automation." The other is molecular biology, the new industry popularly called genetic engineering. The state already has established bases in both technologies. But it wasted no time moving to expand and more firmly root those bases.

The concerted effort has already produced blossoms that in short order will turn to fruit. An early bloomer was the Michigan Technology Fair, first held in Ann Arbor in April 1981. This exhibit showed the high technology capabilities of some seventy Michigan firms and the twenty engineering and scientific departments of the University of Michigan, Eastern Michigan University and Washtenaw Community College. In its two days, the Fair drew 10,500 visitors, some from as far away as New York.

The Fair was held under the auspices of the Technology-Based Industry Committee, an Ann Arbor group established in 1979 to further the region's high technology capabilities. The Committee, since renamed and more broadly based as the Michigan Technology Council, will continue to sponsor the Fair every two years. The next one will be held in April 1983.

"We are promoting the idea that business is healthy for the community," says G. William Ince, Executive Director of the Council. "The people themselves in this area were not aware of how much high technology industry we have."

The privately-supported Council has about 140 corporate memberships. All board members must be from the high technology community, though members at large may be from such supporting businesses as banks. Initially based in Ann Arbor, the Council plans to expand throughout southeast Michigan as a coordinating group for high technology. "Our private funding makes us unique," says Mr. Ince, who came to the Council from a local manufacturer of advanced computer peripherals, Irwin International. "We will get public funding," he says, "and that will be all right so long as the public sector does not dictate to us."

The Technology Fairs show Michiganders what Michigan has in high technology. But the state goes on the road, too. The Michigan Business Trade Fair in Los Angeles in June, 1982, showed the California aerospace and communications industries what Michigan high technology companies can offer them.

Industrial Technology Institute...

One result of the Task Force is the Industrial Technology Institute, or Robotics Institute, now being established at Ann Arbor. The Board of Directors is the Governor's Task Force on High Technology. "This is not just another research center at the University of Michigan," says Arch Naylor, Acting Director. "We mean to create a world-class institute that will be the leader in research and development for the factory of the future."

The state will fund the Institute with $200 million over ten years. "As we get operating," says Naylor confidently, "we expect that industry will also help support the work." Naylor envisions considerable industry involvement so that the Institute will resemble Stanford Research Institute or Battelle. "The idea is that the Institute will do about 30 percent research and the other 70 percent will be work of immediate interest to industry. We will be very much involved in the real world of manufacturing."

The Institute and the state's universities will work very closely with one another as well as each with industry. But though the Institute is just down the road from the University of Michigan and Dr. Naylor is on leave from the school, ITI is not part of the University.

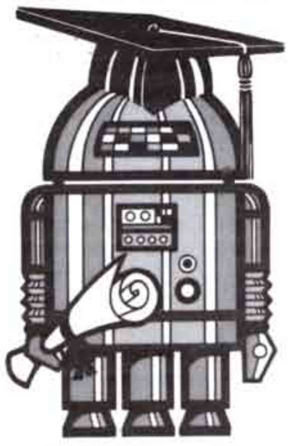
The Institute starts from a good base in factory automation within the state. The University of Michigan, Michigan State University at Lansing, Wayne State University in Detroit, Oakland University and Michigan Technological University in Houghton in the Upper Peninsula all have significant programs in manufacturing technology. "These will all have a meeting ground at the ITI," says Naylor, "and access to our $20 million a year. It would be difficult for any one other entity to match the scale of what will be involved.

"There is a realization that Michigan is in manufacturing," says Naylor, "and manufacturing is going through a revolution. If we don't go along with the revolution, we'll be left out."

University Technical Support...

The schools, indeed, are catalysts that spark the state's further development of its existing technological base and its growth into new areas.

Most of the major universities are state institutions, receiving substantial support from the state. But three of the four major ones, the University of Michigan at Ann Arbor; Wayne State University; the sprawling urban university in downtown Detroit; and Michigan State University at Lansing, the state's Land Grant College, are autonomous. They go to the legislature for funds but not for detailed approval of their budgets and policies. They can therefore move quickly in directions



their faculties think best for their own specific constituencies.

These three are in the Lower Peninsula. Across the Straits of Mackinac in Houghton, Michigan Technological University turns out ten percent of all the mining and metallurgical engineers in the country. The school is a natural for advanced work on natural resources.

Says Dr. Raymond F. Decker, vice-president for Research, "We have proposed to the governor a plan for an Institute of Natural Resources Biotechnology. We expect it will be founded at the University almost immediately. We have the equipment and talent there and can attract more."

Areas of interest include finding and developing new strains of bacteria that can do cheaply what existing processes do expensively. "We will investigate bacteria that will both help trees grow faster and accumulate metals from water and from the soil," says Dr. Decker, who comes to his post from the International Nickel Co., or INCO Ltd. Both would be important to Michigan industries. "Other bacteria could be used to purify water or mine minerals. It would be an extension of existing technology in which bacteria are already used to leach minerals from low grade materials."

As a special mechanism to foster technology transfer, Michigan Tech has organized a venture capital company. Michigan Tech Ventures Inc., will take equity and/or debt positions in new technology-oriented companies. One example is a company making cuprous oxide for paints from recycled electronic circuit boards. Your dead personal computer could end up painted on your boat.

Wayne State in urban Detroit also has an important role. Prof. Calvin L. Stevens, vice-president of research and acting Provost, points out that, "We are situated in an area that can provide inspiration and incubation. We can upgrade jobs and help the unemployed to enter the high technology economy. Our location in the southeast population center helps. Our medical center provides a unique resource to spawn a high technology medical industry." Among the University's projects will be a Metropolitan Center for High Technology specifically oriented toward the manufacturing and product problems in the state's transportation base.

The project is another example of the Michiganders' concern for the future, since it is a product of a local High Technology Task Force established by Wayne State and the Mayor of Detroit. Vehicle electronics will start it off, followed by materials, chemicals, electronics and biomedical.

The University has long been a center for vehicle research, particularly crash testing. "We have one of the leading university research centers for the effects of sudden stops on human beings," says Stevens, laconically.

An offshoot of that is a peculiar Spring ritual among the engineering students. On a weekend in April, a passerby may see students atop the school's parking garage carefully dropping what appear to be eggs. They *are* eggs, packaged, parachuted, sprung or whatever, in the hope they will fall fifty feet or so without breaking. "In a crash," Stevens explains patiently, "the head is most sensitive. If you can protect an egg, you can protect a head."

Michigan State University at Lansing is also a strong resource. Ann Arbor being more the college town than the state capital at Lansing where MSU is located, U of M has tended to overshadow MSU, which was the nation's first land-grant college. A happily displaced Pennsylvanian from the Philadelphia area, MDSI's Henry Apfelbaum tells how he knew for sure he was in a college town. "When the bank gave me a calendar that ran from September to September, I knew." But MSU by its nature is integral to the state's economy, particularly its agricultural sector. As Dr. John Cantlon, vice-president, Research says, "Agriculture is where genetic engineering is really moving ahead. And as for the mechanization of work, one would look far for a better example than the mechanization of agriculture." MSU has formed its own genetics corporation, called Neogen.

The smaller schools, too, are eagerly helping the state to marshal its high technology resources. One, indeed, was founded on the very problem that now troubles the state, but occurred a century ago. Ferris State College in Big Rapids, north of Grand Rapids, was established to instill new skills in people who would be unemployed when the sagging logging industry died.

The school now has about 11,000 students in two and four year courses. "Our primary objective is to develop a skilled labor force," says Dean Joel Galloway. "We are not a research center, but a school for technician and engineering technician training. I have behind me the chambers of commerce, the transportation industry and a hell of a lot of people who make the country run. We are hands-on, laboratory and field intensive. We have a two-year waiting list. And even today, our graduates are almost immediately placed."

Ferris is one of three schools in the state that reflects the state's total population; the other two are the University of Michigan and Michigan State University, according to Dean Galloway. Other schools tend to draw from a more regional student body.

Ferris has its own contribution to make at the level where technology works. It has proposed to the legislature that it establish a Manufacturing Resource and Production Center at the school. Situated in an industrial park at Big Rapids, the Center would serve the industrial community in the reindustrialization of the state. "This integration of industry, faculty expertise and students... would provide a unique resource for the economic prosperity of West Michigan, as well as other out-of-state areas," says the proposal.

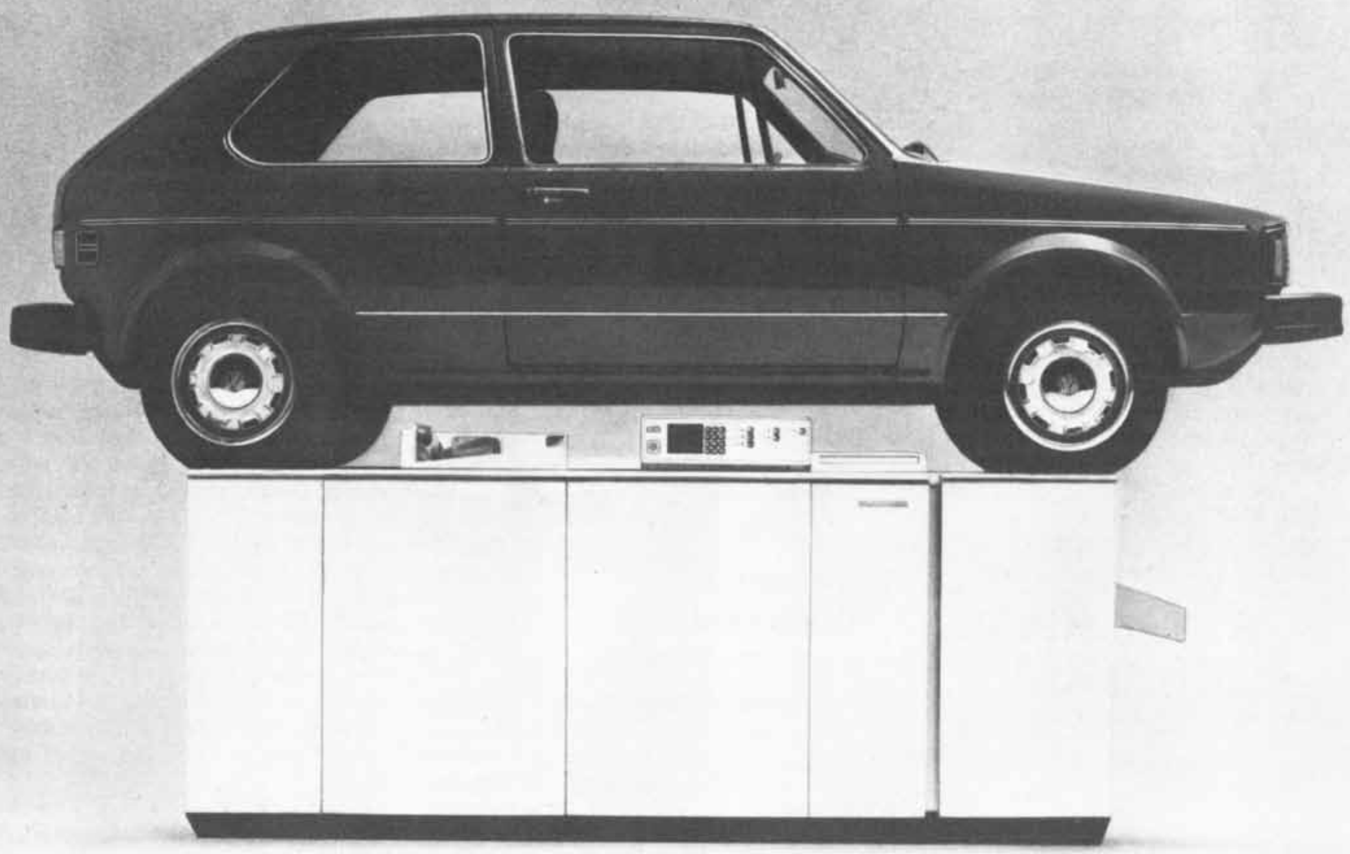
In the same statewide team spirit, the Michigan Council of Professional, Scientific and Technical Associations has prepared detailed proposals for a Michigan Center for Advanced Engineering and Manufacturing Technology and an Applied High Technology Institute Park. This would be a private sector initiative to pool the resources of industry, universities, state and government. Building and land already exist—a 600 acre state-owned tract with a large building readily converted to laboratories and shops.

Michigan Molecular Institute et al...

The state's formal base in molecular biology is less advanced, though there is plenty of progress there, too, centered on the University of Michigan Medical School. There, a molecular genetics center has been formed to speak with one voice across 14 university departments. The center currently has an $8 million budget. Unlike the ITI, whose orientation is avowedly industrial, the molecular genetics center will concentrate on basic research in the field. "The field has developed out of academia," says Dr. Dale Oxender, Professor of Biochemistry at the medical school, "and the pioneering will continue to be at universities. Industry is not creating ideas in this field but buying them. Industries will settle down around the universities."

Four or five companies active in the technology now exist near the University, and several others across the state have a keen interest. These include Gelman Sciences, Inc., KMS Fusion and the Warner-Lambert Co., all at Ann Arbor, the Upjohn Co. at Kalamazoo, Dow Chemical at Midland, and the Michigan Molecular Institute (MMI), also at Midland.

The MMI is a creature of the Midland Foundation for Advanced Research, which is in turn funded by the Family



Foundations, primarily the charitable foundations established by the founders of Dow Chemical Company. In 1964, these groups gathered to consider what technological research would be helpful to Michigan. Six years later, in 1971, having decided, they established the Midland Macromolecular Institute, now the Michigan Molecular Institute, to conduct research into the properties of large molecules. They selected macromolecules because very few scientists were trained in this interdisciplinary field.

The Institute is unusual in that it is privately funded and is not part of a major research university. It is, however, academic in form. Dr. Hans G. Elias, president, heads a permanent staff of ten professors and a rotating faculty of post-doctoral fellows and professional research assistants. "We regard ourselves as fundamental research people," says Dr. Gordon Carson, vice-president and former dean of engineering at Ohio State University. Recent ones cover such diverse areas as ultradrawing of plastics, synthesis of adhesives, and a low-temperature polycondensation process.

The Institute's work covers the entire field of polymer science, a lot of ground. "What's the nature of matter—how do you synthesize it?" asks Dr. Carson. Polymers and plastics, molecular life sciences, even some neurological research are all fit subjects for the unfettered curiosities of the staff. Polyethylene is a macromolecule. So is the protein that forms the shell of a virus or the polysaccharides that coat at least some cancer cells, as a researcher at the Institute has discovered.

For all the patents and the income they could generate, "It is not realistic to consider covering our costs with income," says president Elias, who left the mountains of Switzerland to continue a distinguished career in the rolling plains of Michigan. Grants, research contracts and depreciation cover the Institute's $1.8 million operating expenses. Industry is a strong supporter.

The Institute expects soon to be able to grant degrees in its field. "We want to be an independent graduate school," says Elias, citing several precedents, such as the Wang Institute, the Institute of Paper Chemistry, the Oregon Graduate Center, among others. Though not affiliated with any university, the Institute if approved by the state legislature could grant graduate degrees.

Midland's Contribution...

MMI shares Midland with two industrial giants, Dow Chemical Corp. and Dow-Corning. The Institute is not affiliated with either company, though the names on its Board of Trustees are much the same as those on the Dow Board of Directors.

Thanks to Dow and Dow-Corning, the charming small city of Midland on two gentle rivers has more Ph.D.'s per capita than any other place in the nation. The city of some 40,000 has other differences from most. The professional people live downtown while the clerical and plant people live in the suburbs, often on farms.

But it is the chemical plant, the Michigan Division, that dominates the town. Though no longer the largest division, the Michigan Division has become the high-technology center for the company, focus of its plastics and pharmaceutical sectors. "We have some 900 people in research," says Dr. Ronald H. Yocum, Director of Research for the Divison. These complement another 500 people in central corporate research at Midland and 300 in product research. There are research centers at other locations outside Michigan. "We try to minimize duplication," says Dr. Yocum. "Because of our location, we cannot compete with other parts of Dow for big hydrocarbon-based projects (Michigan has some oil, but not enough to support a major petrochemical industry) so we have targeted smaller, high technology products."

Among these are agricultural products. Particularly exciting are those that would bring the farmer closer to no-till practices. "The more you till land, the more you deplete it of moisture and nutrients," Dr. Yocum points out. "A long-term goal is a coated seed that could be planted at harvest time in untilled land and sprout the following spring—a timed-release seed."

Dow is just beginning to get into pharmaceuticals. The company feels its Michigan-based staff, grounded in manufacturing technology, brings a special expertise to the field in developing processes. Thus Dow too is in the true Michigan technology tradition—manufacturing technology—devising better ways to make useful things from new materials.

As a chemical company on a river near a large lake ("We have no problems with water shortages here," says Dr. Yocum) in an area of great natural beauty, Dow has special concern for the environment. "We do an enormous amount of work in toxicology," says Dr. Etcyl H. Blair, vice-president and Director, Health and Environmental Sciences. "We have had a toxicology laboratory since 1933. Health has never been an issue for Dow." The company was one of 11 founders of the Chemical Industry Institute of Toxicology in North Carolina, now supported by 34 firms.

David L. Rooke, executive vice-president of Dow, is an old Texas hand, San Antonio born, who came to Michigan as president of Dow U.S.A. eight years ago. He views with some amusement the current rush to automate of other industries. The chemical industry is different. "We never had a big labor bill. We put a lot of money, time and effort into automating and computerizing our processes, but the gain was not labor reduction. Rather it comes in better quality, consistency, yield and throughput." The industry is in some ways twenty years ahead of others in computerization. Early efforts to wholly automate production processes were made in chemical plants in the sixties. And there were problems. "We resisted the temptation to jump in all at one time," recalls Mr. Rooke. "We automated one step at a time until a plant or process was completely automated."

As for Michigan, "this area has lots of scientific orientation. The people here really want to do something for the state. We have a tremendous amount of research here and find it a congenial environment for it. Cost of living and housing are not problems. If you want the convenience of a small city with most of the advantages of a large one, this is a good place to be.

"Our opportunity here is as good as any place in the country. And besides, you don't walk away from these kinds of plants. You make them run well."

Sharing Midland with Dow is the grown daughter of a marriage, Dow-Corning, a fifty-fifty joint venture between Dow and Corning Glass Company. The company's products are a unique marriage themselves, between the inorganic chemistry of silicon and glass and the organic chemistry of carbon. The products, generically called silicones, are also unique. Unlike most other substances synthesized by man, nature has never produced a silicon-carbon bond.

Dow Corning was founded in 1943 as a joint venture to exploit the newly discovered silicone chemistry. Dow had the chemical expertise and Corning the silicon technology. "It has been one of the more successful corporate marriages," says Dr. Donald R. Weyenberg, vice-president of research and development. "It was unique in that it was set up solely to commercialize new technology."

Dow-Corning, which itself did over $700 million in sales last year, has a large research and development establishment. "The bulk of our 600 U.S. R&D people are in Michigan. There are research projects beyond silicones, but we see enough in the technology we know and are good at so we don't see any sudden move away from it."

Ann Arbor's Contributions...

In the traditional terms of advanced technology, a more diverse nucleus has grown up around the University of Michigan at Ann Arbor. Here in Washtenaw County are 68 of the 374 research facilities in the state. These run the gamut of technologies, from satellite communications to time sharing, computer peripherals and bioengineering.

Some of the names: ADP Network Services, Comshare, Inc., the Environmental Research Institute (ERIM), Gelman Sciences, Irwin International, Interactive Systems and Sarns, Inc., both divisions of St. Paul's Minnesota Mining & Manufacturing Co., KMS Fusion, Inc., Manufacturing Data Systems Inc., the Facility Management Institute of the Herman Miller Corporation and many more.

...in Medical Technology

Sarns, Inc., specializes in heart-lung machines used in open heart surgery. Says Richard Sarns, who founded the company with his wife in 1960, "We started out to develop, build and sell a quality electro-mechanical product, not specifically in the medical field." But Mrs. Sarns had been working at the University of Michigan hospital "and we became familiar with medical problems. Medical people were frustrated over the transfer of technology to their field. The doctors at the hospital presented us with a list of ten specific needs in medicine that industry could fill. And in 1961 we built our first heart-lung machine to customer order." Mr. Sarns was Chairman of the 1981 Michigan Technology Fair in Ann Arbor.

Mr. Sarns, who is now General Manager of the company he sold to 3M a year ago, attributes the company's success to its long association with the University and the medical school. "There is a tremendous resource here, along with a very good spirit." As for the reputation of the school, "I can go anywhere in the world and mention the University of Michigan and people know what you are talking about."

...in Information Processing

Irwin International Corp. builds state-of-the-art Winchester technology disc drives for computer mass storage. In the business people call the discs "platters." It is a demanding electronic-mechanical technology that most people associate with California's Silicon Valley. Company founder and president Sam Irwin, who has started and sold several high technology companies, explains why he started this one in Michigan two years ago: "I live here."

However, "The University of Michigan made it possible and my being here was probably fortunate. Companies start where people are. The first criterion is getting active industry that has enough people so that other industries can spin off." As for Michigan's technology, says Mr. Irwin, who is chairman of the Industrial Technology Institute board, "We are very good at industrial automation and have a tremendous infrastructure in mechanical manufacturing. If you are in industrial automation, this is where the action is."

...in Fusion Research

Yet another technology not usually associated with Michigan is nuclear fusion. But the world's leading private company in that esoteric field is KMS Fusion, Inc. of Ann Arbor. This company founded in the late sixties by people out of the University of Michigan has about 100 people deeply involved in advanced fusion research, in Project "Chroma." The company developed techniques for making the tiny spherical glass beads used for the implosion laser-energized fusion experiments. In these, high power laser beams zap a microscopic bead filled with lithium deuterium and tritium. The light energy in the lasers, which simultaneously and symmetrically hit the bead from all sides, creates tremendous pressure and temperature, enough to cause the deuterium and tritium to undergo a fusion reaction.

The instantaneous power is enormous. "Our laser produces 2 terrawatts of 1.05 micron infrared light or 1 terrawatt of 0.53 micron green light with which we can generate a quadrillion to 100 quadrillion watts per square centimeter," says Norwegian-born Dr. Erik K. Storm, director of lasers and plasmas at KMS. But not for long—the pulse lasts from one tenth of a billion to one billionth of a second. "KMS was ahead of the national laboratories. We produced the first thermonuclear neutrons," says Dr. Storm.

KMS was founded by K. M. Siegel, a professor at UM and a persuasive visionary who poured his whole substance into the technology. Indeed, he died in 1975 on the witness stand in Washington while testifying in favor of funding for more fusion research. His life insurance paid salaries and kept the company going.

...in Synthetic Materials

Near Detroit, at Troy, is yet another company dealing in esoteric technology that has yet to gain full acceptance. It is, however, drawing close to commercialization and lately has gained a great deal of industrial support. The company is Energy Conversion Devices Corp. (ECD), founded in 1960 and headed by Stanford Ovshinsky.

Ovshinsky's standing in the scientific community stems from his claim to have discovered semiconductor properties in non-crystalline materials—amorphous or "disordered" materials. As with such other controversial theories as Continental Drift, the scientific establishment for many years viewed Ovshinsky's work with scepticism.

A self-taught, self-made scientist, Ovshinsky nonetheless gradually persuaded industry that he did indeed have something. He attracted money and a talented staff. "We are basically a materials company," says Lionel Robbins, vice-president. "Behind it is an area of solid state materials that was not well understood. We amassed a strong patent portfolio while no one paid attention." They pay attention now.

The technology uses different materials for different applications, but always disordered materials. For instance, where standard silicon technology rests on crystalline material, ECD's material is, in effect, supercooled before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YPSILANTI
Willow Run Airport
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ANN ARBOR
U of M
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DETROIT
25 mi.
Huron Center
Detroit Metro Airport
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Whittaker Rd.

it can crystallize. Devices based on crystalline material are limited by the size of the crystals that the manufacturing processes can produce. That limit constrains the size of a single solar cell or the number of devices that can be made from a wafer. Amorphous material can be made any size. ECD has developed a production machine that has produced single solar cells a foot wide and 500 feet long.

Grand Rapids Contributions...

Technology lies not only in materials, processes and conversion of materials to useful products. It lies also in how people do their work. Proper design of the workspace may well have greater influence on productivity than any amount of new high technology hardware and systems. The workspace must fit the way people really work, which is not always the way their supervisors think they should work. Human engineering, or ergonomics, on the production line is well established. Human engineering in the office is more recent. Michigan is a leader in this branch of technology. That is not surprising considering the furniture industry with which Grand Rapids is as synonymous as Detroit is with automobiles.

Indeed, the Grand Rapids industry is no stranger to technology. During World War I, furniture craftsmen built four-engined DeHavilland bombers. Not as big a step as one might think since both furniture and bombers in those days were built of wood and fabric, wire, glue, screws and nails.

Today, offices across the country reflect a technology that adapts technology, the so-called open plan. The rapidly installed, quickly modified modular systems incorporate considerable technology in their own functional and manufacturing design, including CAD/CAM at the Facility Management Institute in Ann Arbor and the parent Herman Miller Company in Zeeland. Herman Miller is perhaps typical of the high technology office systems companies such as Steelcase, Inc., centered in western Michigan around Grand Rapids. "The design of the systems provides an environment for high technology equipment and approach," says Judith Ramquist of Herman Miller. "It can make an incredible difference in the productivity of a person, group or department," she says.

Jim Lear, the legendary high-technology company builder, started his company-building in Grand Rapids. He is memorialized in two major divisions of Lear-Siegler, at Grand Rapids. These are Rapistan and the Instrument Division, which together account for over half the company's 6,500 employees in the state. LSI has many smaller units in Michigan, which also serve the automotive and aerospace industries.

Rapistan designs and builds materials handling systems. The company employs some 1,400 people, over 200 of them technical professionals, in the Grand Rapids area. Materials handling is a high technology sector today that uses image recognition systems to automatically move items from storage to shipping, among other functions. "We can move some 200 cases per minute through a system with computer control," says Chuck Smith, high technology sales manager for Rapistan. "We design the systems first, then put the building around it. The systems double or triple productivity and reduce errors and paperwork." The technology now exists so that a housewife could do all her ordering from home to a computer, which would then select, group and ship the items. "We're noodling it around," says Smith.

The Instrument Division employs some 2,200 people. The division designs and manufactures instrument systems and components for aircraft, missiles and space systems.

Venture Capital Opportunities...

If Michigan has lacked one ingredient that other advanced technology centers have, it is a well-developed venture capital base. Some believe that is neither true nor significant. Jack Wallace of Prab Robots, for one, believes that money will always be available to help people with good ideas bring them to market. And it was not lack of venture capital that kept Energy Conversion Devices struggling in the technological wilderness for so many years.

But Herbert Doan of Doan Resources and Arnold Ott, formerly with Doan and now a consultant to Amway Corp. in Grand Rapids, think otherwise.

Whatever the reasons, these and others believe, the Michigan capital markets have been conservative, oriented more toward the tried and proven than the new and untried.

"We have good skills and wonderful educational institutions," says Mr. Doan. "On that, we should be able to repeat the experience of the Northeast—regenerative economics. But there is no venture capital base. Everybody had a good thing going. So there was no perceived need for venture capital."

Doan and his associates, including Arnold Ott who was then in Midland, formed Doan Associates in 1971. At the time there was only one other venture capital firm, Michigan Capital, formed five years earlier. The company, a Small Business Investment Corporation (SBIC) has since been bought by the National Bank of Detroit.

"The banks had a lack of understanding of smaller business and what they can mean," says Doan. "Take Boston—those guys know venture capital. It would be hard to find anyone there who would question the business generation potential of venture capital." As for the suitability of Michigan as a place to start a business, "An entrepreneur starts a business where he is."

But entrepreneurs are more likely to succeed if there is local capital willing to take a risk and help the management. A superb idea is a starting point. A climate of local support, a base of human, financial and commercial resources upon which the entreprenuer can draw can make the difference between an idea that flowers and bears fruit or one that withers.

Dr. Arnold Ott (a chemist) co-founded Doan Associates but later sold his interest and returned to Grand Rapids. Among other things, he is an advisor to Amway Corporation on corporate development. Amway is a distribution and sales company, among the fastest growing businesses in the nation.

Separately, Dr. Ott has set up Ott Associates, Ltd., which is a venture capital firm. He is also being instrumental in setting up a group of enterpises that together will help entrepreneurs market ideas. These are the Grand Valley State College (GVSC) Venture Fund, Westpen Venture Capital Forum, to bring entrepreneurs and management assistance people together, Westpen Capital Corporation, a community-owned SBIC, and Westgrand Limited, a partnership for business development.

Beyond Transportation...

Michigan accepts the premise that it can never again rely to such an overwhelming degree on one industry, transportation. Yet to assemble the more diverse economy of the future it must build upon what it has.

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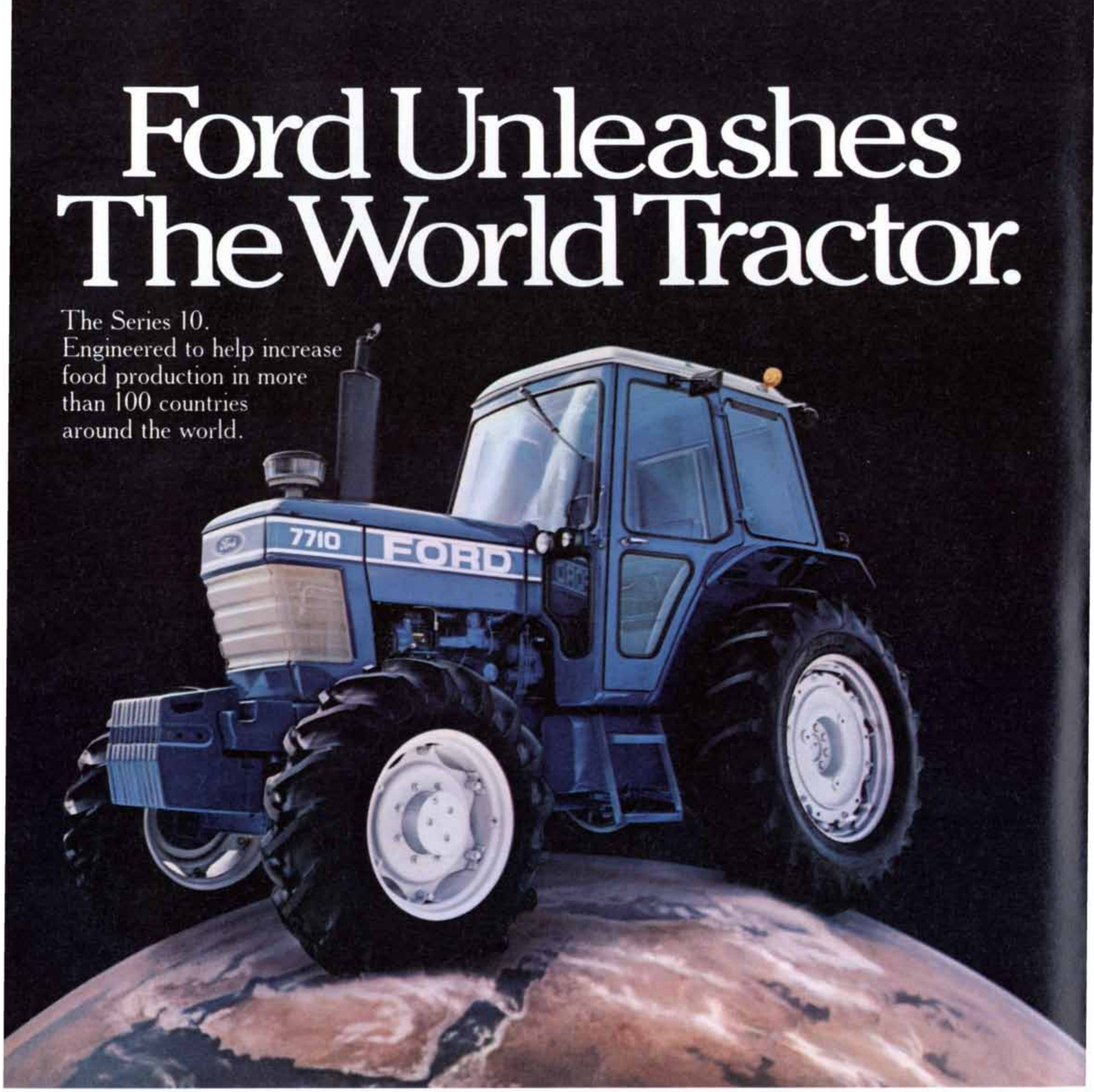
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BOOKS

Nuclear illusions, the quantum code of nature, inexhaustible Darwinism

by Philip Morrison

NUCLEAR ILLUSION AND REALITY, by Solly Zuckerman. The Viking Press ($10.95). Henry Kissinger and Basil Liddell Hart had published their cogent theories. Then came, relates the author of this taut and candid little book, "a series of more empirical studies which, as Chief Scientific Adviser to the British Minister of Defence, I had set in hand early in 1960." He reported to the NATO commanders one summer 20 years ago and published later, to the tune of opposition challenge in the House of Commons. His paper seemed heresy, although it simply summarized the outcome of a series of war games played out on the map of the central German front where NATO forces face those of the Warsaw Pact. It gives us an authentic, if delayed, look at the work of the military planners.

The rule is clear: both forces deploy in anticipation of battlefield nuclear attack. They spread thinly, one "minor unit"—100 men or so, an infantry company, a tank squadron, a battery of artillery—spaced far enough from the next for a nuclear weapon of 15 or 20 kilotons' yield to be needed against each. Experienced divisional commanders called the shots. The advancing "Russian" units were dispersed to about that degree; the entrenched defenders relied on larger yields, one or two bombs per unit. In one game a British army corps could hold its front along the river Weser by firing 130 nuclear weapons but could not hold it by firing only 60. In that example, however, the Russians were assumed not to have resorted to their own tactical nukes.

Another game saw three NATO corps engaged, with nuclear weapons fired only against military targets in an area where there were no large towns or cities. That paper battle lasted a few days. The two sides exchanged between 500 and 1,000 nuclear strikes. With airbursts a couple of million died, more than 90 percent of them civilians; with ground bursts another several million citizens suffered serious harm from radiation. That neutron bombs could make any difference, writes the author, is "a total illusion." Most of the generals received these conclusions rather poorly; they were "'jammed' in most military minds by a barrier of accepted doctrine." The American general Earle Wheeler, then NATO commander-in-chief, seemed to have heard; Field Marshal Montgomery, audacious by temperament, had a simpler view: "I'll strike first and seek permission afterwards." Only conventional forces can hope militarily to defend Western Europe.

Solly Zuckerman is a senior certified expert. He first turned his attention to war from zoology when he undertook searching studies on the epidemiology of blast and shell-fragment injuries in 1942, as one of the most cogent of backroom analysts. This book, not without its facts of life and death, is chiefly a tight and historically supported insider's analysis of nuclear-weapons doctrine and forecast over two decades.

What of strategic war? Perhaps the new accuracy and the new doctrines of war-fighting make a difference there? The U.S. seeks only military targets for its MIRVed warheads, even in retaliation. Our plans in 1979, however, called for no fewer than 60 warheads on Moscow, all marked for military targets exclusively in that capital city. Muscovites are very likely to overlook the subtle courtesies of our Single Integrated Operational Plan when damage circles so grossly overlap around them, even if they have found subway shelter.

The U.K. has prepared at heavy expense (and with much doctrinal inconsistency) an "independent" underseas nuclear force. It now plans an increase, to mount MIRVed Tridents, the new U.S. SLBM's. But the nuclear forces of the U.K. or of France are already big enough to deter, Lord Zuckerman argues, even though they are 50 to 100 times smaller than those of the racing superpowers. Zuckerman, conceding the weighty moral objections, is still for a cautious policy of minimal strategic nuclear deterrence. These weapons, he sees, are "too dangerous to use in war;... while nuclear weapon states might be deterred from turning their nuclear arsenals on each other, the existence of nuclear weapons can neither prevent war nor defend in war." The plausible scale of such a deterrent force is suggested by the four submarines of the U.K.: the cut from current levels is not by a third but fiftyfold.

Zuckerman seems to blame the experts for much of the trouble. It is remarkable to read how the British weapons laboratories preempted decision both with respect to a quite unneeded decoy-and-evasion program (costing a billion pounds) for their Polaris missiles and to the planned deployment of Trident by the Royal Navy. In both cases designs and tests were under way before the ministers heard the news. Yet consent followed under each government; the "politicians have to run hard to catch up with the scientists." One exceptional leader is celebrated: Harold Macmillan, the prime minister whom the author once served. He had set his mind on a comprehensive test ban. "I told [Eisenhower] that we ought to take risks for so great a prize. We might be blessed by future ages as saviors of mankind, or we might be cursed like the man who made *il gran rifiuto*." The literary Mr. Macmillan here alluded to Dante's description of the refusal (abdication) of Pope Celestine V.

The Partial Test Ban ensued, a valuable environmental treaty but not what Macmillan wanted and no impediment to the R&D game. It all happened again in the late 1970's. We got no comprehensive test ban in part because the experts found many objections; they always can, and their leaders apparently fear to take risky action. The absurdities are manifest; neither Edward Teller in the 1960's nor Harold Agnew in the late 1970's can claim in hindsight much more than posturing for their concerns. "The nuclear balance had not been affected in any way by refinements in warhead design."

Not reason but rationalization rules nuclear doctrine, today even more than 20 years ago. The 1980's are time for a new effort, a reviewer infers, if we are to avoid the grim glowing catastrophe. That campaign must be—as it is—in the press and on the screen, in the streets and at every front door, in the lobbies and indispensably at the ballot box. *Il gran rifiuto* is now the public's.

THE COSMIC CODE: QUANTUM PHYSICS AS THE LANGUAGE OF NATURE, by Heinz R. Pagels. Simon and Schuster ($16.95). It has been about 50 years since the golden decade that gave birth to quantum mechanics culminated in the formulation of the quantum theory of fields. The author of this sparkling account of what has come of it all is no veteran of the old days, still wrestling with meaning; he was not yet born when Heisenberg, Pauli, Jordan and the rest were able to merge classical force fields with quantum particles into one entity obedient to relativity. Rather he is one of the young participants in quantum theory's modern triumphs, and he flies its banner with the élan born of recent victory. "The essential reality is a set of fields," whose interactions, ordered by a hierarchy of symmetries, determine by the rules of quantum probability all the particulate events the experimenters detect. There isn't anything else. That central dogma rules now, although lightly, because these physicists are first of all creative pragmatists, willing to submerge their most cherished preconceptions when something new works well and yet does not destroy long-won positions.

The book has two parts and a brief coda. The first part is an exposition of what quantum physics means, loosely set in the context of the history of physics from Einstein to Heisenberg and Bohr. Those strange demands of quantum physics on its students—its dualism, its noisy uncertainties, its frank paradoxes, all the "quantum weirdness"—are here entered through the door of randomness, a familiar concept that nonetheless holds the very pitfalls for which quantum theory so often takes the blame. Not for nothing does Professor Pagels refer to code; indeed, the best practical codecraft of today is only an applied antinomy of randomness. The ciphered text is a string of random numbers, able to pass every sampling test of randomness. Yet it is trivially decoded, given an equally long key. It is made, say, by adding to the string of numbers that spell out the plaintext a long key string of random digits one by one. That sum is as random as the key and nonetheless as meaningful as the plaintext. Its information lies neither in the key nor in the cipher but in their cross correlation.

Is 314159 random? It is too easy to guess. But what about 203048? Taken from a much later and less familiar segment of pi, its meaning would be very hard to find. Pagels carefully extends this simple and striking idea into a persuasive rebuttal of the deep critique of quantum mechanics that stemmed from the 1935 objections of Einstein. Quantum particles, once they are correlated by interaction, may retain their correlations after long separation. This holds true even when an experimental choice remains open at a given location long after one of the particles has passed by. Even granting that the distant record changes suddenly with the local choice, nothing is gained or lost; only the correlations of two random sequences are affected. That knowledge is real, but it is intrinsically nonlocal; it resides jointly in the cipher and the key.

This part of the book closes with a dream sequence based on the alternative realities that quantum physics appears to support. Neither a new quantum logic nor a local reality nor a simple objectivity, all touted in the philosophical marketplace, wins our author. He is drawn to the old man with a pipe and a Danish accent who watches the bustle from a little distance. His "presence projects both warmth and confidence." For that man reality is none of the easy wares on sale; quantum reality is not to be fitted into any of the classical boxes of the philosophers. The competing reality shops belong to brothers; the two views are at base complementary. Nothing is ultimately hidden from us, yet no quantum weirdness enters the world of large atomic samples where we perforce dwell. We can occupy only one room at a time in the house of reality. The entire episode reminds a reader of the concurring dream recounted in another fine popular discussion of quantum reality by J. M. Jauch, reviewed here a few years ago.

The second part of the book begins with the manifest quantum result that the decisive matter microscopes of our times, the big accelerators, are not the devices of minute size one might expect on the basis of classical physics. Obedient to the quantum relations, they are huge tubes and magnets fit to guide the high-energy particles that alone can have wavelengths short enough to probe the microcosm. Pagels then takes us on a voyage into matter, from atoms to quarks to field theory to novel symmetry. Here too he manages a tour de force of explication without mathematics, sketching at some honest level even such difficult ideas as gauge theories and renormalization.

Attend in particular to the vacuum. There randomness means *nothing at all on the average,* yet it demands fluctuations that have tested consequences: transient distributions of positive and negative charge, forces of attraction between smooth metal plates very close together, even the dominant sources of energy, it may be, of the entire early universe. The old ether was banished by Einstein; surely it is back, surprisingly relativistic, when even Professor Pagels, nothing if not the modern, suggests that empty space can be viewed as the seat of a number of super-3-D mattresses of "tiny invisible springs." Once upon a time, quite particle-free, they may have been all that was made.

A critic finds a little to argue with here and there, in the treatment of identity, or around thermodynamics and exchange forces, or the omission of some helpful experiments, such as the experiment of the forces between metal plates analyzed by H. B. G. Casimir. The book is nonetheless a reliable guide for the nonmathematical reader across the highest ridges of physical theory. Pagels is unfailingly lighthearted and confident; if he does not allow quite enough chance to look down or to try other paths, it is all the better for safe climbing. Matthew Zimet's good-humored and personal drawings lighten the climber's load. Good mountaineering is always exhilarating but a little brash.

DARWIN TO DNA, MOLECULES TO HUMANITY, by G. Ledyard Stebbins. W. H. Freeman and Company ($28.95). Sow and resow your field with a mixture of varieties of a single crop year after year. Markedly inferior strains, little suited to the circumstances, quickly disappear. Yet other inferior varieties, perhaps at not so much disadvantage, persist indefinitely. Even a well-tilled flat field is not uniform in detail; it holds many microenvironments, in some few of which the less-regarded seed found itself adaptively at home. The pool of genes remains diverse, even under such strong selection. Such a subtle process is far from that sentimental and tendentious old vision of reddened tooth and claw.

Or take it that some major trait, say size, is controlled by many genes. Each individual of a long-surviving population may hold about as many genes that code for increased size as those that code for decreased size. Natural selection has led in such a case not to evolution but to balanced variation. Around the normal forms all the familiar processes of genetic shuffling, mutation and survival add the noise inescapable in such chancy events. Plainly a new environment would shift the population to quite new forms, even without molecular replacement. The most rapid episodes of change in the fossil record move slowly by the generational clock. In general it is not mutation that drives evolution; rather mutation is to be counted on for some of the necessary noise.

The changes that so strongly mark the current of life are the result of prolonged interaction between the pool of genes, steadily stirred by a variety of processes, and the flowing environment, which of course includes other living forms, whose coevolving nature is often decisive. Novelty can arise when some novel challenge enters the stream, out of all the diversity of the natural world; yet the new arises only as it is constrained by the legacy of the old, those inner variations latent in the long-edited tapes of heredity. It was J. B. S. Haldane who explained that the human species would "never produce a race of angels; genes for wings and for moral character are not present in human populations." That we human beings nonetheless do fly in great numbers is also under inquiry in this engaging book.

Professor Stebbins is a senior evolutionist who has taken unusual pains to prepare a popular survey of today's synthetic theory of evolution. He not only brings to bear his long research experience and his evident flair for reflective generalization; he also updates the state


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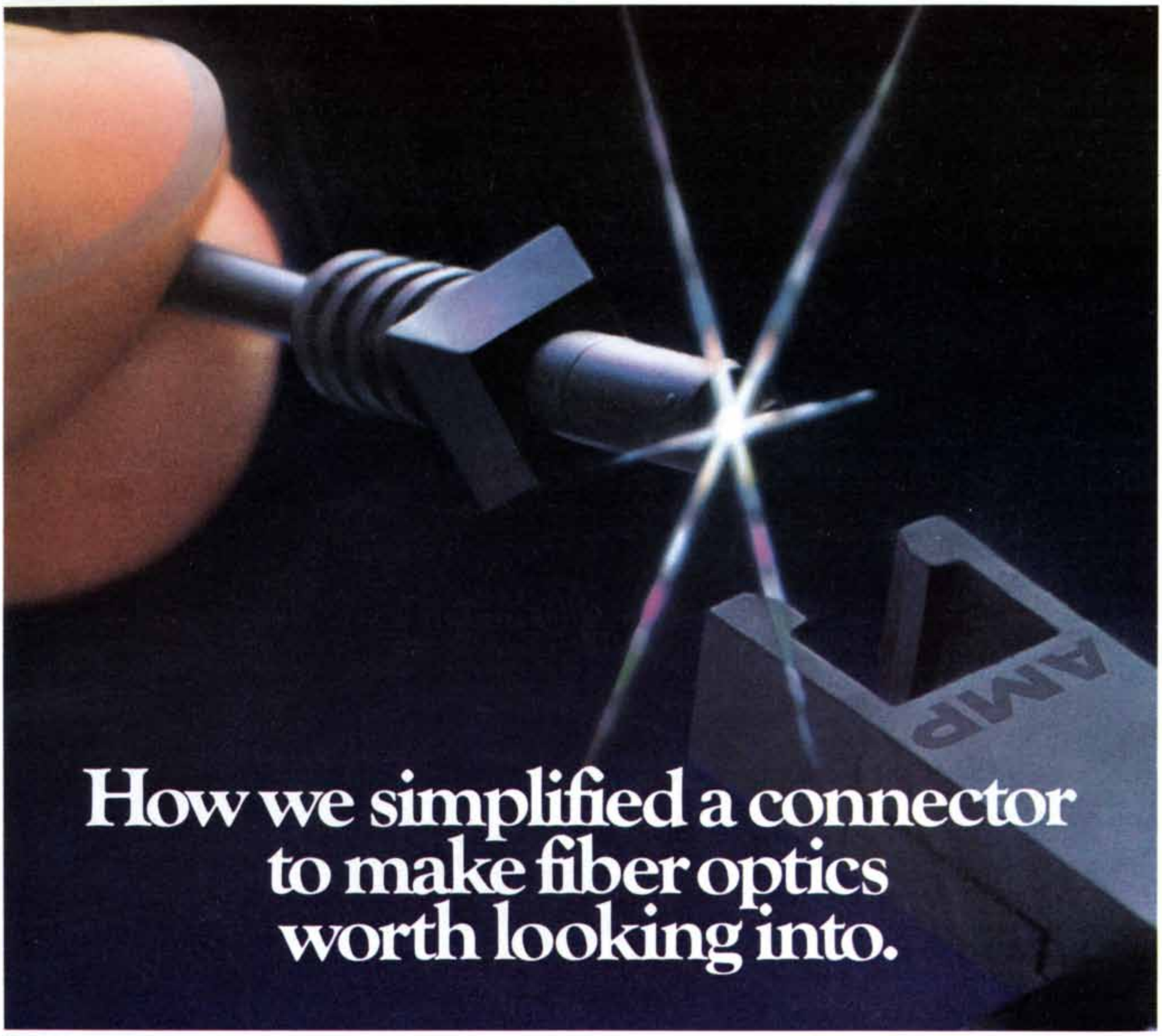
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of the science by explicit accounts of recent advances and evenhanded summaries of issues in the current literature. We of course still fall short of a consensus in full understanding. The somewhat awkward title implies the ambitious goals of the well-illustrated volume. Its three major parts treat first the process of evolution itself, then the major events of the long evolutionary path from the rise of bacterial forms through biochemical versatility to the occupation of the land by life and the coming of the primates, and finally the biological and unique cultural evolution of our own species. The last two chapters take an evolutionist's look at human history and a modestly hopeful glance into our future.

A general reader is sure to be caught in particular by Stebbins' expert discussions of plants, the other big multicellular kingdom. That the big trees are old individuals is a commonplace. In fact, sod-forming plants, such as the buffalo grass of the dry prairie, may be still older, with some clumps perhaps still creeping along from a time of seeding after the glacial ice first thawed. Some plants have no need to die at all; only disease or changing climate may bring their end. It is not absurd, although it is speculative, to think of individual sod plants somewhere in the Tropics as being now millions of years old.

Death arises in animals out of requirements for size, mobility, symmetry, compactness. Animals grow from an embryo that fully differentiates. The sedentary plant is more irregular overall, growing more and more leaf surface as it ages. Embryonic tissue remains at the stem tips, in the oldest and largest plants still able to differentiate. The complexity of plants reaches its highest point in the reproductive parts, say in the orchid. This complexity, however, is far less than that of the ingesting and perceptive head of most animals. A simple plant, for example a big green alga, may be complete after the differentiation of four or five distinct types of cells, including the sex cells. In mammals the fertilized egg must differentiate into some 250 types of cells. The first land plants seem to have arisen from an extended layer of green single-celled soil microorganisms, some of which developed into flat, tissuelike multicellular forms, never rising more than a few inches above the moist substratum. Tall stems came later; new structural inventions were needed.

Evolution is a mosaic of rates and tendencies. Complex cells such as our own long ago incorporated tiny symbionts that retain their own heredity, subcontractors now indispensable for several functions. The proteins may evolve at one rate, visible structures at quite another. In chimpanzees and human beings, lobsters and crabs, enzymes are much the same. The protein sequences of two frog species with much the same body plan may differ more than the sequences of human enzymes differ from those of the apes. We are not close to a molecular understanding of the control of development in multicelled animals.

These wide-ranging pages open a measured view of sociobiology and a sustained commentary on the relation between steady progression and a series of quantum changes in evolution and in culture. Readers will be grateful for the dryly reassuring remark that since human beings resemble our commensals, rats and feral dogs and cats, in a stubborn resistance to adversity, we are likely to persist "as long as the earth's environment is capable of supporting large animals."

HOUGH'S ENCYCLOPEDIA OF AMERICAN WOODS, by E. S. Harrar and F. W. White. Robert Speller & Sons, Publishers, Inc., 30 East 23 Street, New York, N.Y. 10010 (16 volumes of ring-bound wood samples, $50; text volumes 1–8, $25 each; text volumes 9–16 in preparation). Franklin Hough, a physician in Lowville, near Albany, N.Y., who laid the groundwork for the profession of forestry in America, and his son Romeyn, an ingenious naturalist, became fascinated by accounts of a German collection of thin cross sections of various woods. In 1886 Romeyn Hough patented a clever machine for cutting similar samples and proceeded to make and sell decorative printed cards of paper faced with the thin sections. The firm prospered; it still exists and sells its Cards of Wood from Belmont, Mich. (49306), sectioning more than 100 species of wood on his original machines, with appropriate improvements. Romeyn Hough also devoted a lifetime to elaborating a synoptic *Encyclopedia of American Woods* with real samples species by species until his death in 1924, when he had over the years issued piecemeal a dozen volumes. They were prized in their time (every normal school in the state of New York was issued a copy of the first volume by the authorities), but the scale and slowness of the work has meant that few complete sets are to be found. The research behind the books was not, however, in vain; Hough brought out several less ambitious compendiums that saw wide service.

In the 1950's the present publisher discovered enough stock of those remarkable old wood sections to prepare 1,000 copies of the treatise. For such an ambitious work, however, the text was badly dated. Professor Harrar, late of Duke University, a wood scientist of distinction, prepared a new text to support the wonderful samples of 385 American trees, including a couple of dozen of the most important introduced and naturalized forms. His work extended over the

eight volumes now in print, 200 species from Eastern white pine to Royal Paulownia, from date palm to Sitka spruce. Now a Duke colleague of his, Professor White, has undertaken to finish the remaining text in the coming few years, almost 200 species more, including poison sumac and saguaro.

Each species is represented by three neatly mounted sections, 10 centimeters by four, a tenth of a millimeter thick, easy to view from both sides. It is striking to tilt transverse sections before the light; the collimated parallel tubes within the wood pass light freely only as long as they are not much inclined to the line of sight. Radial and tangential sections complete the display. Microscopic examination is easy and rewarding. All the sections were taken by Hough from small rough timber samples he tirelessly sought out. He verified their identity with meticulous care in the herbarium and in the field.

Each of the sample volumes offers about two dozen species, three sections to a page in a ring binder. The text for those species is presented in a slender bound companion book, half a dozen pages for each tree, many with a range map. Consider two trees of nearly 400, the Eastern white pine and the West Indies mahogany. The first, its tall, straight examples marked out in the colonial forests with the king's broad arrow, long furnished the Royal Navy with spars and masts, planking and decks. The largest conifer of the Eastern woodlands, it once spread from Maine to Minnesota, and south along the mountainsides to Georgia. From 1631 this 100-foot tree was the principal source of lumber in the hemisphere: house frames and shingles, fence rails and fence posts, heavy bridge timbers across the stream. The long harvest peaked in about 1890; then the species faded away with the frontier. Pine stands are found now on the abandoned upland farms reverting to forest, but the great forest is gone. The soft, light, easily worked wood holds screws and nails well; its last major use was in the making of boxes and crates while those were still common, its color and light weight fit for that purpose even when knotty second-growth material belied the memory of Lord Nelson's masts.

As that pine is white, so is the mahogany deeply dark. The tracheal openings stand out strikingly in section. This wood was found by Columbus himself; on his second voyage he admired a well-made canoe of the strange bronzy wood and shipped timbers back to Spain. Before long the galleons of the Spanish Main had decks and hulls of mahogany; the Armada's wrecks brought the wood near English shores. It was the prizes taken by English privateers that first supplied mahogany to Britain. From Philip II's Escorial to the Georgian London craftsmen around Chippendale and Hepplewhite the finest cabinetry is mahogany. The trees grow sparsely, one or two per acre in rich virgin jungle. Once they were found in southern Florida, but the loggers' greed has ended them there, at least in commercial sizes. Plantations are growing up for this stable, smooth-working and richly colored wood. The sections here are handsome, and we are told in the expert's phrases that mahogany's stump wood and crotch wood, "when sliced on a stay-log, produce some of the most handsome figures known to the face veneer industry." Indeed, the text is mostly quite technical, in particular in its botanical descriptions of the trees and in its accounts of the wood itself, both in gross appearance and in microscopic view.

This ample encyclopedia is patently not for everyone, but it is a treasure of bookmaking, the legacy of a century of scholarly energy and devotion and a paradigm of technical documentation, reaching beyond symbol and icon to collect between its covers a representative sample of the natural world in all its unmatched variety.

A PICTORIAL GUIDE TO FOSSILS, by Gerard R. Case. Van Nostrand Reinhold Company ($29.95). The giant skeletons stand tall in the great museums, the articulated fruit of decades of expeditionary zeal and preparatory patience. Long cases hold innumerable labeled shells and imprints of strange marine forms; some of them draw for a moment even the casual visitor. Many more fossils crowd the quiet rooms of the working collections. There the specialists painstakingly sort and compare, measure and draw. These are the documents of the fossil record, to be interpreted, published, criticized, the basis of a science that is indispensable to our understanding.

Paleontology must of course begin out of doors, peering and hammering, along the road cuts and stream beds in New Jersey or South Africa. Worldwide there has grown up a volunteer weekend army of amateur collectors of fossils. These men, women and children seek out, trade and prize the commoner documents of past life in a simple vein, wide-eyed, covetous and hopeful. From that army of irregulars keen professionals are often recruited, and sometimes a thoughtful amateur, far from vocational enlistment, finds and recognizes a major new page in nature's narrative. The amateur is generally less specialized in interest, although more visual, less concerned both with hidden pattern and with the technical niceties.

This volume of more than 1,300 pictures is the compilation by a collector for collectors but is eye-catching for any reader. Its sweep is broad: about 50 brief chapters, arranged by biological divisions from protozoa to rodents, present fossils worldwide over nearly all the

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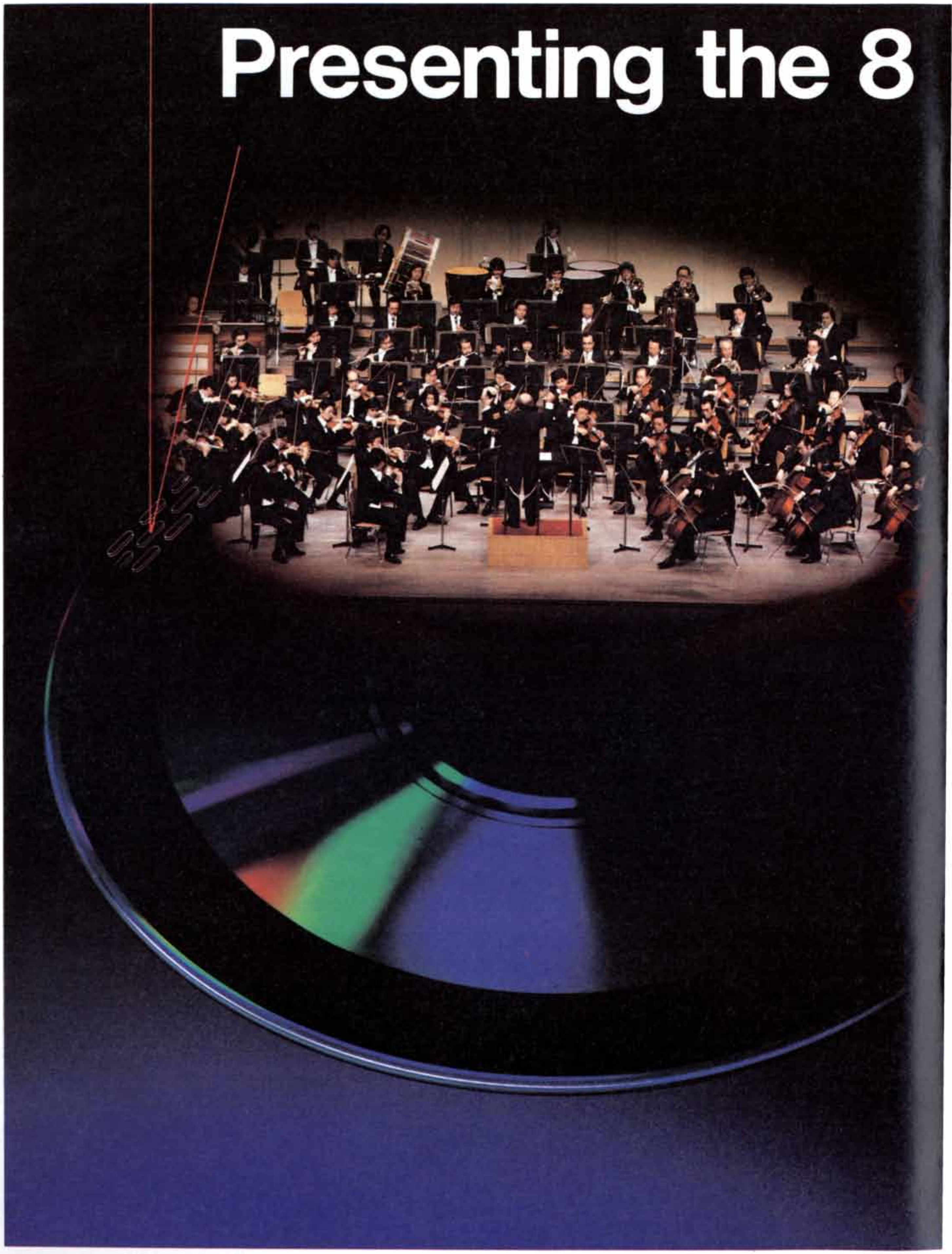
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billion bit symphony

Conventional discs are incapable of preserving "live" sound

Despite such innovations as stereophonic discs, linear tracking and microcomputerized amplifiers, modern Hi-Fi systems still rely on the analog method of sound signal recording that Edison invented in 1877. Sounds are inscribed on a disc surface as changes in amplitude of grooves, and these grooves are subject to wear during play, which causes gradual deterioration of sound quality. What's more, analog records have a number of inherent drawbacks — wow, flutter and distortion — which make it impossible to recreate the richness and clarity of the original sound even with the best audio equipment.

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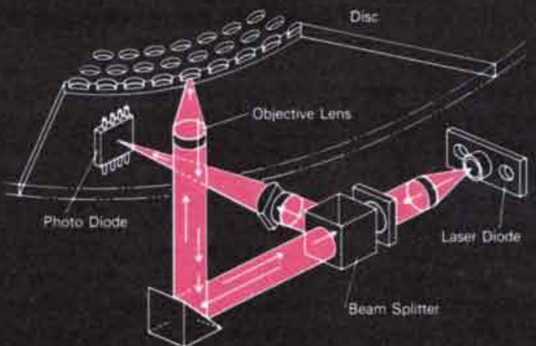
By bringing together diverse technologies, Hitachi has been able to develop the world's first commercially available Digital Audio Disc (DAD) player, a system employing mirror-like discs just one-fourth as large as standard LPs. In recording a DAD symphony, for example, every passage of the original performance is sampled several thousand times per second. Each sample is assigned a 16-bit code, which is in turn printed on the disc surface as a series of reflective pits, some 8 billion of them per one-hour disc side. You might think of each pit on the disc as proportionate in size to a grain of sand in a large concert hall. In playback, these pits are read optically by a laser beam and reconverted into music by an LSI chip, with no wow, no flutter, and only 1/200 of the distortion heard on ordinary discs. Dynamic range and S/N ratio have been boosted to over 90 dB. Plus, there's no wear whatsoever, because nothing but light comes into contact with the DAD surface.

Unique method of laser tracking

To ensure accurate tracking during playback, the laser beam, which measures a mere 0.5 μm in diameter, must be perfectly focused on the pits within ±0.1 μm of dead center. Slight imperfections in the disc track have been known to cause mistracking in digital players under development elsewhere, so Hitachi engineers came up with a unique method of splitting the laser beam into three parts — one to read the recorded music signals and two to serve as corrective guides. In all, Hitachi collected some 140 patents and patents pending in the course of creating DAD equipment, which is certain to revolutionize existing concepts of high fidelity.



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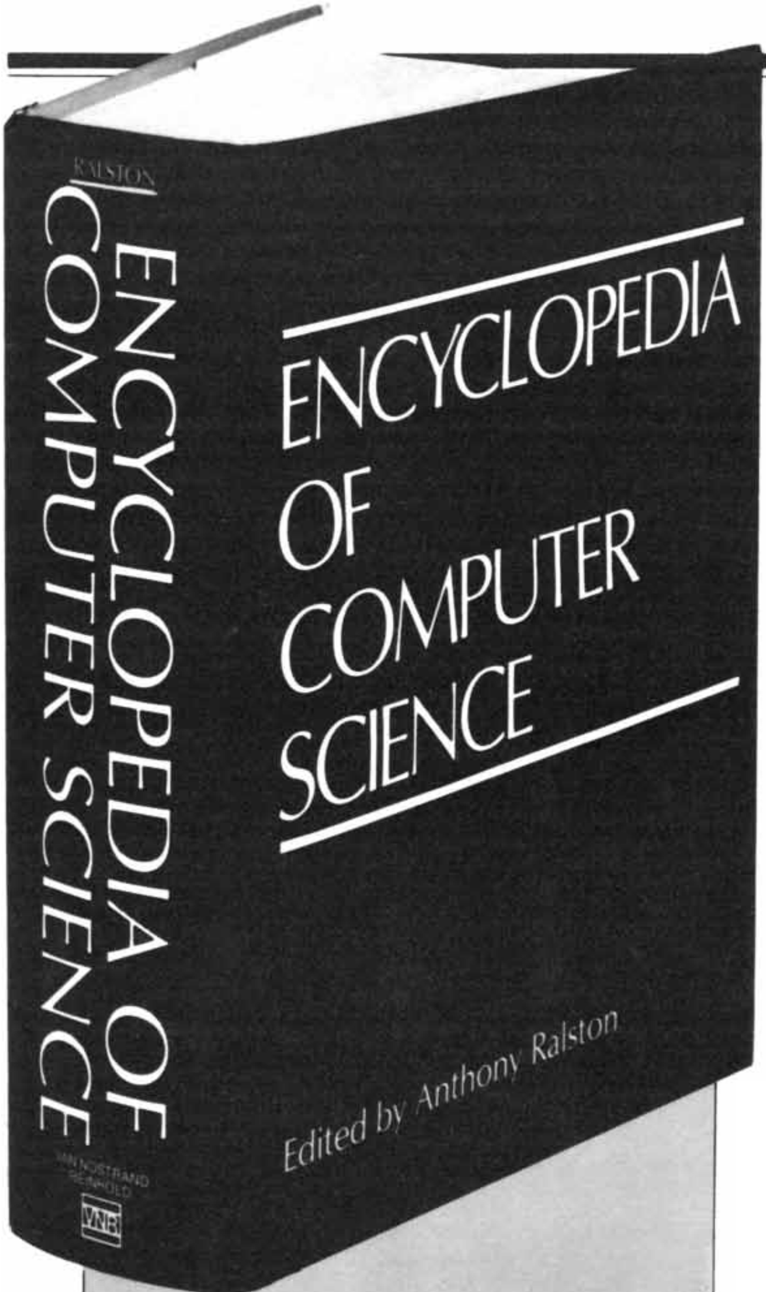
major forms of past life. Some of those shown are microscopic but most are roughly the size of a hand. The wealth of the museums is not ignored, particularly for the larger forms. Most of the photographs, many of which are striking, were made in private collections or in those of the international dealers in fossils who buy, hold and sell again the finds of the more persistent and fortunate amateur and semiprofessional searchers of the rocks.

The result is comprehensive, although it emphasizes fossils that are accessible, much prized and immediately attractive. This is not the place to conduct a careful examination of an evolving line, nor the place to learn much of the function of some ancient organism. But if you would become familiar with a wide diversity of life forms, arranged in simple ordering, this book has few alternatives. The author has been a collector for 20 years. He stands between the camps; he has published several previous compilations and has worldwide contact with amateur and professional, the literature and the tales.

What can you find here? It includes a gregarious group of big trilobites, a frog in amber, an entire glen of reeds and ferns, a school of a 100-odd little herring from the Wyoming Eocene, many elegant creatures in lithographic stone, a New Zealand ammonite from the Jurassic resembling a six-foot tuba of rock and the strange tooth whorl of a Permian shark (or is it—tongue in cheek—a set of dorsal-fin spines?). Most of the space is given to the illustrations and careful captions, always including the scale. There are brief chapter summaries of the nature and importance of the class or order shown, many with remarks about collecting sites or notable finds. Tight-set lists of families or genera are frequent; they are nearly unreadable but will help a collector seeking an identity who wants to consult the voluminous taxonomic literature through these references.

The horseshoe crab is seen over four pages of illustrations, from today's crawler in Raritan Bay to one locked in the Devonian slate of Germany, little changed. There are quite a few museum restorations, in two dimensions and in three; one remarkable set presents a formidable flightless bird of the Argentine Miocene, painted, modeled and in actual skeleton. It is the generosity of the evidence that distinguishes this approach; a collector believes and delights in the diversity of the past. Understanding can grow. Many museums and specialists are acknowledged as the sources of pictorial matter and of information, and some 50 private collectors "were most helpful." The provenance of every illustration can be identified with some effort; the photographers and artists are often the proud and fortunate collectors themselves.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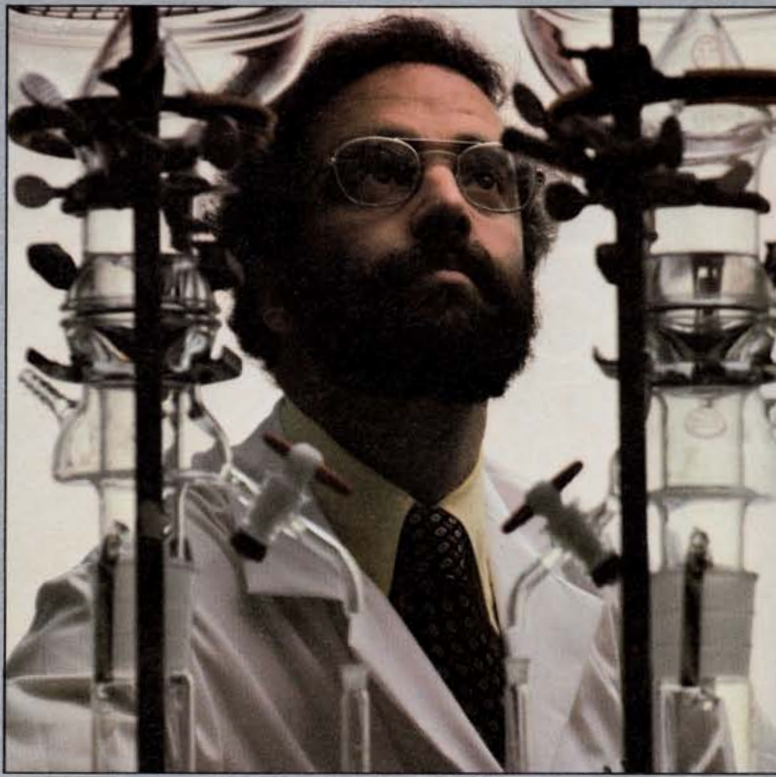

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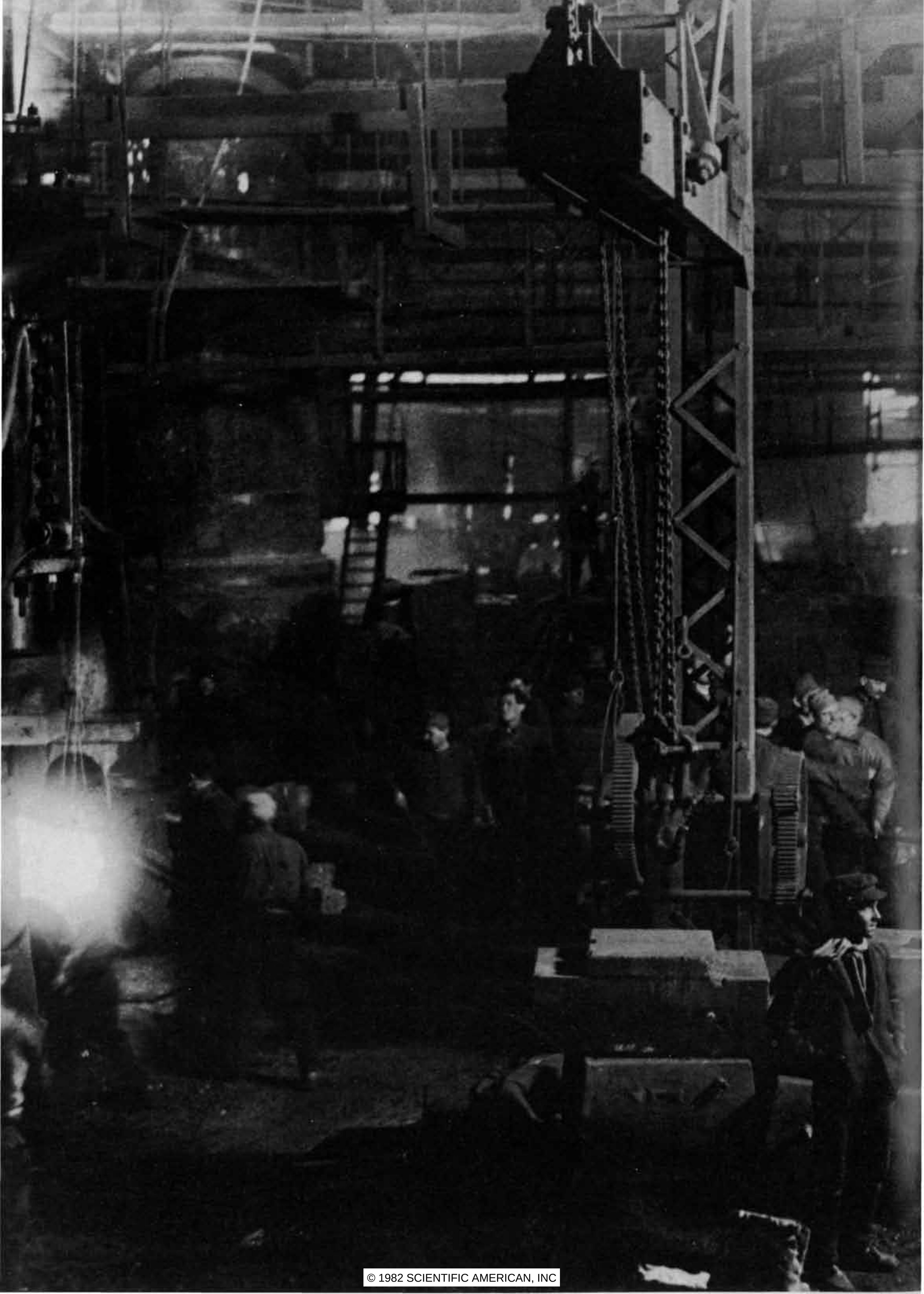

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The Mechanization of Work

Introducing an issue on the continuing Industrial Revolution two centuries after it began. In the U.S. it has now displaced two-thirds of the labor force from the production of goods

by Eli Ginzberg

The easing of human labor by technology, a process that began in prehistory, is entering a new stage. The acceleration in the pace of technological innovation inaugurated by the Industrial Revolution has until recently resulted mainly in the displacement of human muscle power from the tasks of production. The current revolution in computer technology is causing an equally momentous social change: the expansion of information gathering and information processing as computers extend the reach of the human brain. This issue of *Scientific American* is devoted to the latest stage of the historic process that has led from the most elementary force-transmitting machines to the most advanced information-handling ones.

The transformation of the U.S. labor force in the country's brief history tracks the progressive mechanization of work that attended the evolution of the agrarian republic into an industrial world power. In 1820 more than 70 percent of the labor force worked on the farm. By 1900 fewer than 40 percent were engaged in agriculture. Half a century ago, when the capitalist societies were sliding into the Great Depression, more than half of the U.S. labor force had shifted from the production of goods to the provision of services. It was then, as large-scale unemployment destabilized those societies, that national policy began to look at employment as much from concern to ensure the consumption of goods as from concern to secure their production.

Today employment in the services in the U.S. is approaching the same 70 percent that were bound to the soil a century and a half ago. Only 32 percent of the labor force are still engaged in the production of goods (mostly in manufacturing), and a mere 3 percent are employed in agriculture.

Although this transformation has been brought about largely by mechanization, it has been accompanied by social trends so pervasive that they must be included among the causes of the transformation as well as among its effects. For example, although women had begun to enter the labor force from the beginning of the Industrial Revolution, by 1980 they had come to make up 43 percent of it [see "The Mechanization of Women's Work," by Joan Wallach Scott, page 166]. The age of entry into the labor force has risen, reflecting the desire of Americans for more education and the higher level of training required by jobs in the increasingly sophisticated economy as well as the release of human labor from the tasks of production. In 1940 the median number of years of school completed by the younger members of the population was 10.3; in 1980 it was 12.9.

A disquieting feature of these dynamic internal shifts in the labor force has been the persistence of high levels of unemployment among its less educated members. Such unemployment raises the question of how any society can function effectively over the long run without bringing all its adult members into its economic life, able not only to work but also to buy [see "The Distribution of Work and Income," by Wassily W. Leontief, page 188].

The five articles that follow take up the technologies of mechanization in five areas: agriculture, mining, design and manufacturing, commerce and office work. This introductory article will of necessity deal with a limited number of themes: how the mechanization of work has been treated by economists, what its effect has been on the U.S. economy over the past few decades and what its future effect is likely to be. Particular attention will be paid to the impact of mechanization on the shifting structure and character of the labor force and on the evolution of the work environment.

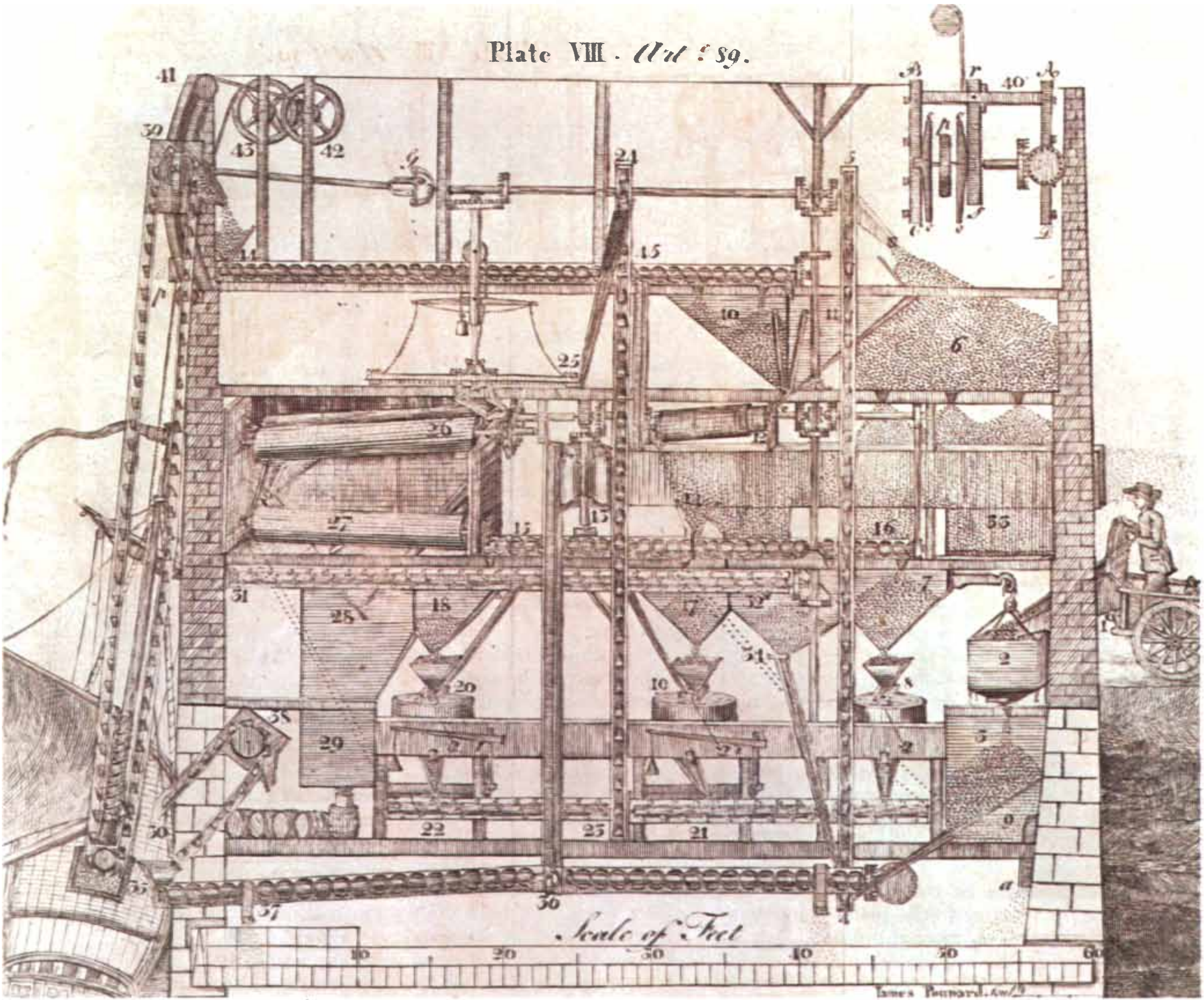
Adam Smith, in *An Inquiry into the Nature and Causes of the Wealth of Nations,* published in 1776, pointed to a basic dilemma: efficiency in the generation of wealth is enhanced by the division of labor, and yet specialization that involves nothing more than routine, repetitive tasks diminishes the worker by depriving him of intellectual challenge and decision-making responsibility. Smith, preoccupied with issues of moral philosophy, expressed his concern that many workers, in a desperate effort to improve their economic circumstances, would drive themselves so hard that it would affect their health and even shorten their lives. Smith's book was written before the commercial success of James Watt's steam engine, and so Smith never had to confront the full force of modern industrialization. He nonetheless appreciated the close links between the work men do and the quality of their lives.

David Ricardo, who began his study

WORKERS AT A STEEL MILL in Pittsburgh were recorded by the noted documentary photographer and social reformer Lewis W. Hine in about 1910. Hine's revealing images of the adverse conditions of industrial labor in the early decades of this century were instrumental in the enactment of laws governing occupational safety and the employment of children. Much of the work being done by human muscle in this scene is now done by machine. The photograph, which is from the archives of the National Child Labor Committee, is now part of the Edward L. Bafford Photography Collection of the University of Maryland Baltimore County.

of political economy after reading *The Wealth of Nations* in 1799, went on to establish the classical, or free-market, school of economics. In spite of his almost exclusive emphasis on the competitive marketplace, he cautioned that increased reliance on mechanization might not turn out to be an unqualified blessing. He could see that under certain conditions workers displaced by machines might not be able to get new jobs. What was good for the employer, he concluded, might be bad for the worker.

Karl Marx devoted some of the most telling chapters in *Das Kapital* to describing the adverse effects of mechanization on the minds and bodies of working men, women and children in mid-19th-century Britain. (Because women and children received lower wages they were then replacing men in many branches of industry, from coal mines to textile mills.) According to Marx, the combination of machines,



MECHANICAL FLOUR MILL patented by Oliver Evans of Philadelphia in 1790 has been described as the world's first automatic factory and the forerunner of the modern continuous production line. This schematic diagram is from *The Young Mill-Wright and Miller's Guide,* published by Evans in 1795. The mill could be supplied with grain from either a boat or a wagon. In the latter case the wagoner dumped the grain into a spout (*1*), from which it flowed into a scale (*2*) for weighing before falling into a small garner, or granary (*3*). The grain was then led to a vertical bucket conveyor (*4, 5*), which raised it to the top floor. There a crane spout could deposit it in the main storage garner (*6*), from which it could be directed into a hanging garner (*7*) that in turn fed a millstone (*8*) for rubbing, or shelling, the grain before it was ground. The rubbed grain ran by a special channel (*broken lines*) back to the first garner, where the chaff was blown through a screen into an adjacent room (*9*). The grain was again elevated to the top floor, and the crane spout was turned this time over a pair of screen hoppers (*10, 11*), which fed a rolling screen (*12*). From there the grain descended through a current of wind made by a fan (*13*). The clean, heavy grain fell through a funnel (*14*) into a horizontal screw conveyor (*15, 16*), which distributed it uniformly to the three hanging garners (*7, 17, 18*), maintaining a constant flow of grain to the millstones (*8, 19, 20*). The ground meal was moved by another screw conveyor (*21, 22*) to a second bucket conveyor (*23, 24*), which emptied it into a rotary structure called the hopper boy (*25*); this device in turn spread the meal to cool it, sweeping it gradually through holes in the floor into a room called the bolting chest, where it was sifted by a set of rotating cloth sleeves called bolting reels (*26, 27*). The superfine flour collected in a packing chest (*28*) and was led out through a spout (*29*) to fill the barrels, which could then be loaded on the boat (*30*). The coarsely ground material was removed by another screw conveyor (*31*) to a garner (*32*), which also collected the light grain blown by the fan; the chaff was driven farther by the wind and fell into a separate chaff room (*33*). The coarse material was recycled by passing it through a gate (*34*) to the bottom of the first elevator. The grain supplied by boat could be unloaded from the hold by several methods: by an articulated screw conveyor (*35, 36, 37*), by a short bucket conveyor with a fixed upper pulley (*38*) or by a long external elevator (*39*) leading to the top floor. The pulley of the external elevator was designed to rise and fall in a pair of curved slots (*41*); the mechanism for hoisting the elevator clear of the boat (*42, 43*) is shown in another view (*40*). A screw conveyor on the top floor (*44, 45*) moved the grain into the mill. Evans finished the first model of his mill in 1783, and two years later a full-scale operating version was built at Red Clay Creek near Wilmington, Del. He promoted his invention vigorously, maintaining that his improved milling machinery "lessens the expense of attendance by at least one half."

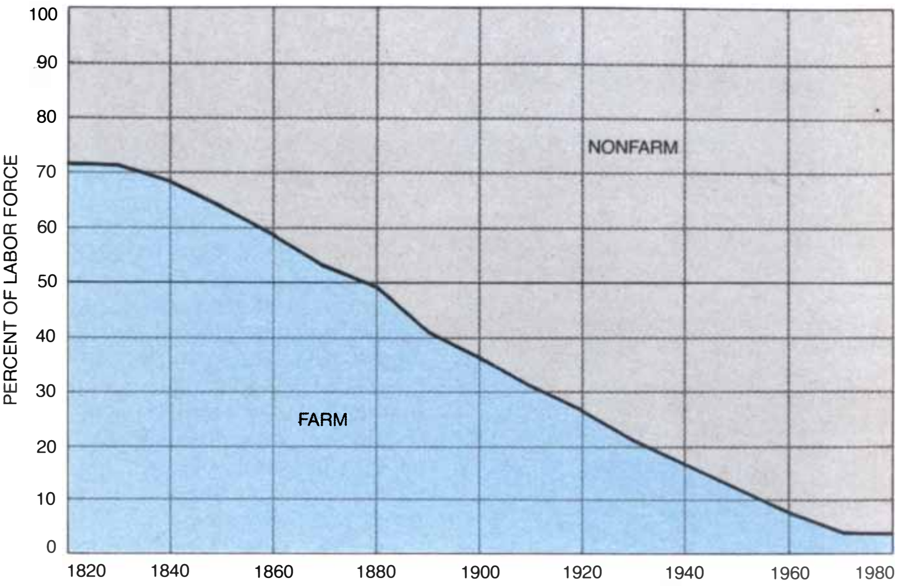
private property and competition would soon result in the self-destruction of the capitalist system. The end would come, he said, when newer and more powerful machines would drive such a large proportion of the labor force out of work that producers would no longer have enough consumers to buy the goods their machines were turning out. With the advantage of hindsight one can now see that Marx was better as a critic than as a prophet. He correctly perceived that the Industrial Revolution was harming millions of working people, but he did not allow for the substantial gains in well-being they and the generations of workers after them would enjoy because of the increased productivity resulting from mechanization.

Thorstein Veblen made technology the basis for his own penetrating analysis of modern capitalism, from his first major work, *The Theory of the Leisure Class,* published in 1899, to his last, *Absentee Ownership and Business Enterprise in Recent Times,* published in 1923. Veblen consistently maintained that the way work is organized to suit the requirements of machines determines how men think, act and dream.

In general, however, most economists—free-market, Marxist or otherwise—have failed to give technology its due. The classical theorists and their successors have built their systems and their reputations by explicating with ever greater subtlety how demand, supply and price interact in competitive markets to establish or reestablish equilibrium. To pursue this static line of inquiry they have had to ignore the influence of such dynamic factors as changes in demography, technology and taste. Moreover, because they have a limited view of efficiency they search for the margin where it pays an employer to install machines to replace workers but seldom look into such factors as the quality of the workplace and the home, both of which have come increasingly under the influence of machines.

The shortcomings in the economists' approach to the mechanization of work can help to explain many of the errors in perception and action that have characterized the U.S. economy in the period since World War II. A better understanding of the complex relations between mechanization and the economic process can be gained by reviewing some of the more important of these misperceptions and the inadequate policies they have engendered.

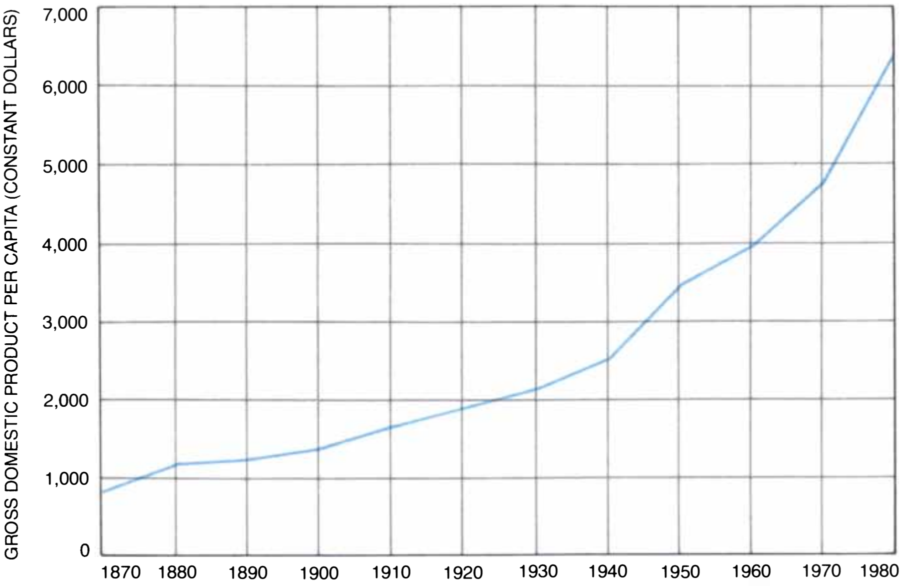
In 1947 the U.S. instituted the Marshall Plan. If the countries of Western Europe—both the victors and the vanquished—could agree to work together, the U.S. promised to provide them with the capital needed to speed the rebuilding of their devastated economies. Within a few years the economies of Western Europe had turned around and were growing rapidly.



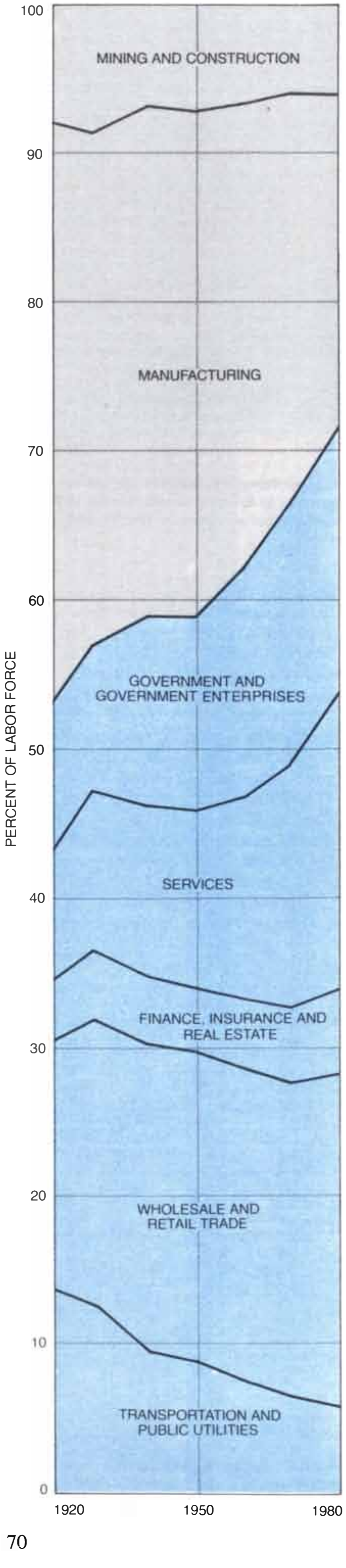
HISTORIC DECLINE in the fraction of the U.S. labor force employed in agriculture reflects the high degree of mechanization achieved on the farm in the past century and a half. In recent years agriculture in the U.S. has actually become more mechanized than manufacturing.

The success of the Marshall Plan had much to do with the inauguration of smaller-scale programs of economic assistance designed to accelerate the industrialization of the less developed countries. They too became the beneficiaries of American capital exports. Here, however, the record of accomplishment turned out to be much less impressive. Little of the so-called economic assistance went to economic development. Instead American capital exports often went in the form of arms and American dollars added to the personal wealth of those in power. Only in retrospect has it been possible to understand the reasons for the difference in outcomes. In Europe the war had destroyed factories, power plants, railroads and other facilities, but the knowledge required to run an industrial economy had remained intact. This knowledge, accumulated over a century or more, was drawn on to make good use of the new machines as soon as they were installed. In most of the Third World there was no such pool of experience, and as a result many of the imported machines were installed only after considerable delay; frequently they were operated far below capacity, and they were poorly maintained.

A second example of failure to bring



GROSS DOMESTIC PRODUCT of the U.S. has continued to rise at an approximately constant rate, when measured on a per capita basis. Nevertheless, there is considerable concern about the recent sharp decline in productivity, measured as a function of units of labor input.



GROWTH OF THE SERVICE SECTOR of the U.S. economy is represented in color on this graph for the period 1920–80. The subcategories indicated cover all wage and salary workers (including full- and part-time workers) employed in nonagricultural establishments. Included are workers in the nonagricultural goods-producing sectors (manufacturing, mining and construction) and those in the service sector, defined in the broadest sense to encompass all enterprises not engaged in the production of goods. (The subcategory "Services" is narrowly defined to designate those workers who provide services primarily to consumers.) Excluded (besides farm workers) are proprietors, self-employed people, domestic servants and unpaid family workers.

mechanization into the center of economic policy is provided by the U.S. automobile industry. Until its recent troubles that industry was looked on as the bellwether of the American economy, proof that the U.S. was the technological leader among the developed nations. Year after year the industry's sales and profits were large, and although working conditions in the assembly plants were often unpleasant and arduous, the work force was well paid and received excellent benefits. The misperception of what was happening in Detroit resulted from a widespread failure to recognize that the industry's continuing high profitability rested primarily on styling, advertising and marketing, not on advances in engineering and in manufacturing technology.

In 1962 Congress, convinced that mechanization was resulting in the disemployment of many skilled workers who would never be reabsorbed into the labor force unless they could be helped to acquire new skills, passed the Manpower Development and Training Act. That act, together with its successor legislation, the Comprehensive Employment and Training Act (CETA), passed in 1973, led to the expenditure of more than $80 billion up to the beginning of the Reagan Administration, mostly to help the poor and the near-poor. It is doubtful, however, that even 1 percent of the outlay was directed to the retraining and reemployment of workers who had lost their jobs through mechanization, because such workers could until recently make their own way into new jobs.

The most recent example of confusion about the mechanization of work arises from national economic policies ostensibly directed to "reindustrialization" (for example tax cuts for accelerated depreciation of plant and equipment, a measure expected to start a new boom in investment). The U.S. is urged to pursue other policies, public and private, that will putatively enable it to regain its eroding leadership in the manufacture of a wide range of industrial and consumer products, from steel to automobiles and television sets. Much is made of the superiority of Japanese management and the dangerous decline in the productivity of U.S. industry. However the issue is formulated, the core elements are the same: the leadership of the U.S. in technology has slipped, and there is a serious dysfunction in the attitudes, behavior and output of American workers.

Actually the available statistics suggest that on a per capita basis the U.S. is close to its long-term trend in gross domestic product (G.D.P.): the output of all domestically produced goods and services. The unease centers on the recent sharp decline in productivity (measured as the ratio of total production to units of labor input). Any interpretation, however, is plagued by complications: the reported hours of work overstate the actual hours worked, exaggerating the measured declines in productivity; the U.S. economy has been shifting rapidly from goods to services, a shift that inadequately reflects the increases in output; the statistics also fail to adequately reflect changes in quality, investments in the public sector and what is happening outside the market, notably in the "underground economy" and in the household. If one were to understand and take proper account of these developments, the performance of the U.S. economy would probably be better, and possibly much better, than the current statistics suggest. Americans may well be unduly worried over a phenomenon that reveals more about the limitations of economic analysis and statistical reporting than about the economy itself.

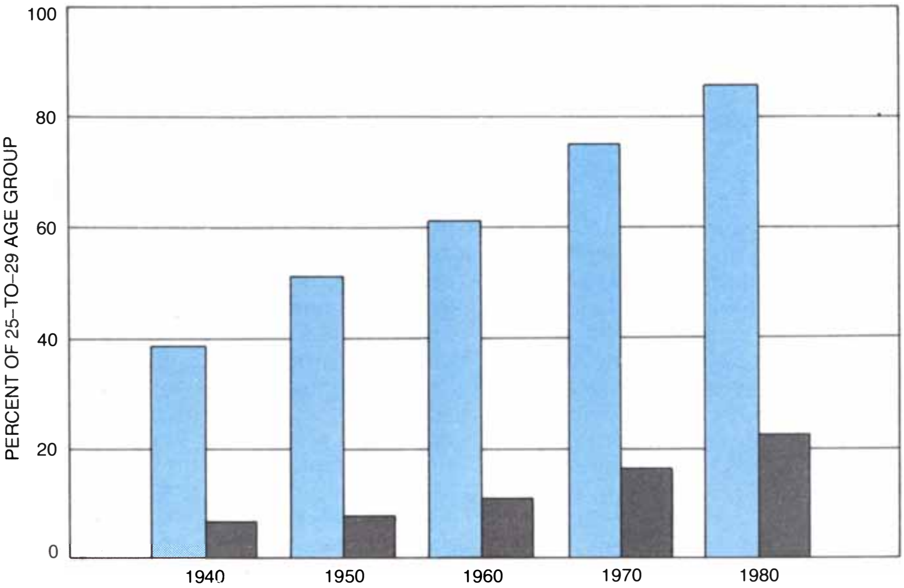
The fact remains that mechanization has continued to play a leading role in the transformation of the U.S. economy and other developed economies in the past half century, as it did in the preceding century and a half. New and better machines have contributed to reducing the average weekly hours of work in manufacturing from 44 in 1930 to fewer than 42 today. At the same time mechanization has contributed to major gains in the rewards for work: the average pay in manufacturing has risen from $1.60 per hour then to $3 now (in constant 1967 dollars). This excludes fringe benefits, which have grown on the average to about 35 percent of base pay. Moreover, some economists have come to appreciate that the key to economic progress lies less with the accumulation of physical capital and more with the broadening and deepening of human capital, since it is human talent alone that is capable of inventing, adapting and maintaining machines.

Part of the problem is that the majority of economists, with their strong bias in favor of the competitive market, have paid inadequate attention to the contribution of the public sector to accelerating the growth of human capital. Public support has taken different forms: the

"G.I. Bill of Rights" of 1944, the expansion of public higher education, Federal financing of research and development, and the large-scale proliferation of specialized training programs created as by-products of efforts to build up the country's military strength and to develop nuclear power, aircraft, computers, spacecraft, communications and other large-scale technologies.

In the three decades between the election of President Eisenhower and the election of President Reagan both per capita disposable income and family income, expressed in constant dollars, almost doubled. Trade unions have become a prominent feature of the industrial landscape (although their membership as a fraction of the total work force has declined since 1955), and a professional, college-trained cadre of managers has taken command of most U.S. corporations. It would be surprising indeed if, mechanization aside, the foregoing changes had not left their mark on how workers behave both on the job and off it.

Other factors must also be taken into account: the repeated involvement of the country in foreign wars, the growing threat of nuclear war, rapid changes in basic values and behavior involving aspects of life from sex to religion, increasing skepticism about and challenges to authority and legitimacy. Only those economists who believe everything in life is determined by the calculus of the marketplace would attempt to explain the difficulties in which the U.S. economy finds itself in 1982 as resulting from a collapse of the work ethic. The Luddites looked on the machine as the villain; the supply-siders blame the worker.



EDUCATIONAL ATTAINMENT of the U.S. population has risen markedly in the past few decades. The colored bars indicate those in the 25-to-29 age group who have finished four years of high school; the gray bars correspond to those who have been graduated from college. Between 1940 and 1980 the median number of school years completed rose from 10.3 to 12.9.

The second of the three themes I mentioned at the outset is the extent to which mechanization has helped to change the U.S. economy since World War II. Of the 41.6 million people employed in 1940 (excluding the self-employed and domestic servants) 54 percent were engaged in the production of goods: in agriculture, mining, construction and manufacturing. Mechanization had earlier made steady advances in the grain-producing states of the Middle West, but it had only a minor place in the cotton culture of the Southeast. The South, in the view of President Roosevelt, was the nation's No. 1 economic problem. It conformed to the Marxian view that surplus labor would be concentrated on the farm, living at the margin of subsistence and awaiting an opportunity to relocate to urban centers when employers needed additional workers. As late as 1940 four out of five black citizens were still living in the South, the majority of them on farms they sharecropped.

World War II was the continental divide. Many blacks went into the armed services; others moved to the North and West, where employers faced growing labor shortages; still others moved into Southern cities, many of which were being transformed by the infusion of military dollars. Other farming areas also sustained a large-scale exodus of surplus labor, setting the stage for the accelerated mechanization of agriculture. Paradoxical as it may seem, agriculture is now considerably more mechanized than manufacturing.

In the same four decades mechanization made rapid advances in bituminous coal mining as a result of two factors: the development of strip mining in the West and the decision of the United Mine Workers' Union, led by John L. Lewis, to favor higher wages over more jobs. In spite of the widespread belief that strong unions have inhibited mechanization in the construction industry, the evidence from the mechanization of excavation to the prefabrication of structures points to major advances in the application of sophisticated technologies. Although some construction unions have been strong enough to delay the introduction of new machines or to prevent the new machines from operating at full capacity, these delaying tactics have in certain instances stimulated the growth of nonunionized industry, where contractors were able to mechanize without interference.

At the height of the war boom the goods-producing sectors of the U.S. economy accounted for 69 percent of the employed labor force. In 1980 they accounted for 32 percent. The most striking shift in the goods-producing sectors was the decrease in the number, both absolute and relative, of agricultural workers. The second most prominent shift was the relative decline in manufacturing, where employment increased from 34 percent of all nonagricultural jobs in 1940 to 41 percent in 1943 but declined to 22 percent at present.

The decreasing employment in the goods-producing sectors of the economy was first matched and then exceeded by the increasing employment in the service sector. Between 1940 and 1980 employment in service occupations grew from 46 percent of total employment to 68 percent. Of all new jobs added to the economy from 1969 to 1976, 90 percent were in services.

What are the reasons for this shift? The answers differ depending on who is asked. Some economists deny that a significant shift has occurred; at most they will agree that there has been a slow, steady growth of service-sector jobs. Some acknowledge that a shift has occurred, but they ascribe it primarily to the explosive growth in health, education and related services. They expect that the growth will level off and even decline now that the birthrate is down and the Reagan Administration is pressing to reduce the level of Government outlays. Others, including our own group at Columbia University, are convinced that there has been a tilt of demand toward more consumer services and that, even more important, changes have been made in the way goods are produced, calling for a vast expansion in "producer services." Thomas M. Stanback, Jr., and his colleagues at Columbia, in their recent book *Services/The New Economy,* note that the value added of producer services alone—financial, legal, accounting, marketing, management consulting and communications—

equals the value added of all manufacturing output.

A look at the changes in the occupational structure further illuminates the causes and consequences of the shifts identified here. Somewhat simplistic comparisons can be made among white-collar workers, blue-collar workers and service-sector workers (narrowly defined as those who provide services primarily to consumers). In 1940 the proportions employed in these kinds of occupation were respectively 31 percent, 57 percent and 12 percent; in 1980 they were 54 percent, 34 percent and 12 percent. Bigger and better machines on the farm, in the mines, in the factory and at construction sites call for fewer operatives. In modern oil refineries, chemical plants and steel-fabricating mills there is a great deal of machinery but there are few workers, and many of the workers are engaged in white-collar jobs. The General Electric Company, which manufactures tens of thousands of different items from turbines to electric-light bulbs, has no more than 40 percent of its employees directly engaged in production; the rest work in what can best be classified as in-house producer services from accounting to marketing.

If one looks at the qualitative changes that are suggested by the shift from blue-collar to white-collar employment, one finds a truly impressive growth in the two groupings in the standard categories of the Bureau of Labor Statistics that have the highest status and incomes: professional, scientific and technical workers, and managerial and administrative workers. Between 1940 and 1980 the former group increased from 7.5 to 16 percent of the employed labor force, and the latter group declined from 20 to 13 percent. The last two figures conceal a major qualitative transformation, since they lump the owners and managers of small enterprises, whose numbers declined, and corporate and other high-level administrators, whose numbers rose.

Confirmation of the radical changes in the occupational structure can be found in the striking rise in the educational achievements of the younger members of the work force: those between 25 and 29 years of age. One need not hold the philistine view of many human-capital theorists that educational preparation is determined solely by the estimates people make of their career and income prospects to see that the two factors are definitely correlated. The large increase in the proportion of those in the 25-to-29 age group who have either an undergraduate degree or a higher degree is striking: from one in 16 in 1940 to almost one in four in 1980.

There is a bias among economists going back to Adam Smith that only work resulting in a physical output is productive and that services, which are by their nature ephemeral, are unproductive. Smith, reacting to the excessive number of family retainers among the rich, misled himself and his followers about the nature of services. Economists finally realized, however, that an artist who gives pleasure to thousands or a surgeon who restores the health of hundreds must be considered productive. Nevertheless, the followers of Smith have been preoccupied with refining the manufacturing model. With few exceptions the output of services has been downgraded or ignored.

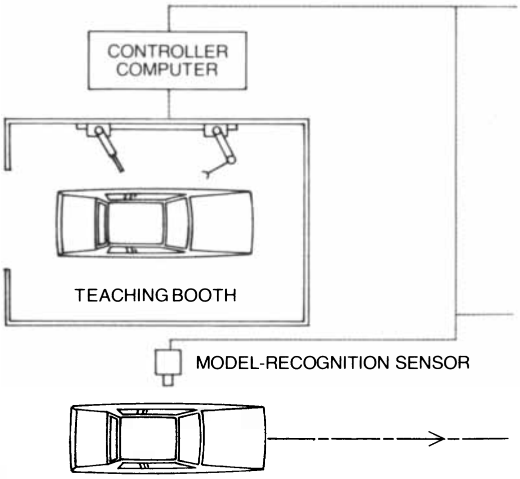
This bias against service occupations was reinforced by a widespread belief that mechanization, the key to productivity and growth, has little or no role to play in the production of services. In fact, some contemporary economists have separated out the heavy, capital-intensive services—transportation, communications and electric-power utilities—and treated them as either part of or closely related to conventional manufacturing.

A further bias has been at work. Many services are anchored in the public sector rather than the private sector; the leading examples are education, health and such basic functions as police protection, fire protection and sanitation. Economic theory based on the competitive marketplace has little to contribute to an understanding of such public services. Handicapped by tradition, economists have been slow to understand the shift of modern economies toward services and in particular toward services in the public sector, toward producer services and toward mechanization in large service enterprises.

Most economists assumed that service companies would inevitably continue to be small, since service providers had to interact personally with consumers, as in the case of a restaurant, a dry-cleaning establishment, a physician or an accountant. The model of the small local consumer-service company, however, clearly does not fit the fast-food chains, the international banks with branches in 100 or more cities, the worldwide hotel chains, the national retailing chains and many other national and international service enterprises that have been able to mechanize many of their critical functions, from finance to personnel management.

As I have noted, the period since World War II has also been marked by a steady advance in the educational preparation and skill level of the work force, as exemplified by the increase in the number of white-collar workers and of professional, scientific and technical workers. The question remains of whether it is more difficult in the service sector than it is in the manufacturing sector to move from a less desirable job to a more desirable one. Stanback believes this has been the case. He points to the steelworker who began work in the yard and could move up many grades on the basis of seniority and on-the-job training. That is not the case, he observes, for the laboratory technician in a hospital or the paralegal worker in a law firm. In support of this argument, it has to be conceded that a college or professional degree is a prerequisite for competing for many of the best jobs in the service sector. On the other hand, talent appears to be as important as formal degrees in many occupations, such as advertising, design and sports. In my view the issue remains open.

These last considerations are a bridge to the third theme I mentioned at the outset: the effects of mechanization on the work environment. To the extent that any generalization is justified, one can maintain that the conventional attitude of the American worker toward machines has been different from that of



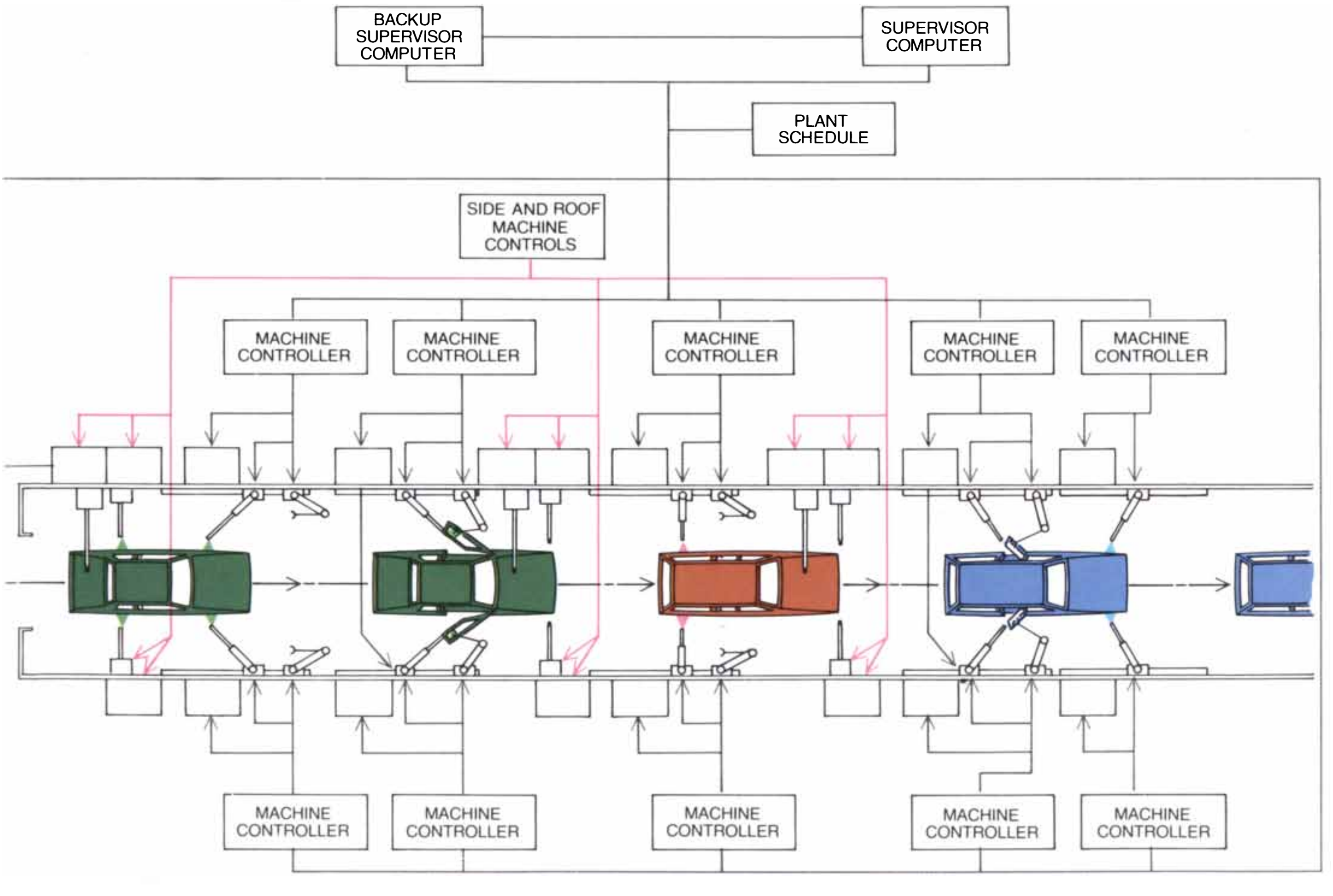
TOTAL MECHANIZATION of a new system for the spray painting of the bodies of cars and light trucks makes it possible to remove all human workers from a particularly onerous industrial task. The diagram shows the control hierarchy for the Numerically Controlled Paint System, which has been developed over the past seven years by the General Motors Corporation; the system has recently been installed at the GM assembly plant in Doraville, Ga. The present system consists of three pairs of automatic, fixed-stroke, roof

the European worker. For the most part American workers have had a positive attitude toward technological improvements, seeing them as making their work less onerous and as providing an opportunity for wage increases through increased productivity and for the enhancement of their job security through improvement of their company's competitive position.

In European countries, with their smaller markets, the job-displacement potential of the new machines has been more prominent in the thinking and action of the workers. Technological unemployment was viewed as a serious threat by the principal unions in the German Weimar Republic of the 1920's, and even the economic revival of West Germany after World War II did not dispel this fear. In the early 1960's the largest of the West German unions, the metalworkers, were host to a week-long international conference on mechanization and the involuntary unemployment it could cause. The issue is once again high on the agenda of the West German trade unions, particularly because of the disturbingly high level of unemployment in that country.

Marx railed against the dehumanization of work in which the machine set the pace, a theme that was resurrected in succeeding generations by John Ruskin, Edward Bellamy and Emma Goldman and that was developed perhaps most imaginatively in Charlie Chaplin's motion picture *Modern Times.* One need not gloss over the physical and psychological strain of working on the assembly line to point out that at the peak probably no more than one in 15 or 20 American workers earned a livelihood by such work. Robert Schrank, whose *Ten Thousand Working Days* is the most perceptive account of the diversity of working environments in the contemporary U.S. economy, makes a strong opposing case. Instead of the machine's dominating the lives of the workers, he writes, the immediate work group learns to organize its activities to enlarge its scope of freedom to do the things its members most enjoy: swap stories, fool around, play games, gamble, keep the foreman off their back and otherwise interact with one another, investing little of themselves in carrying out their assignment.

Three decades ago, in the book *Occupational Choice,* my coauthors and I distinguished three returns from work: intrinsic (direct work satisfaction), extrinsic (wages and benefits) and concomitant (interpersonal relations on the job and in the work environment). Advocates of improving the quality of work life see major opportunities to enhance the intrinsic and concomitant returns that workers are able to get from



and side sprayers of a type already in wide use for such painting operations, five pairs of numerically controlled paint machines (four pairs equipped with door-opening devices) and an off-line teaching booth that houses another numerically controlled painter with its associated door opener. (The number of painting stations is expected to vary from plant to plant; one system currently being installed has 18 of the new machines.) The numerically controlled painter is a seven-axis device, hydraulically driven and servomechanically controlled. Its function is to paint all external body surfaces and various internal surfaces not covered by the roof and side sprayers. The machine's reach enables it to paint bodies of all sizes, ranging from subcompacts to full-size sedans, station wagons and pickup trucks. The painter's companion, the door opener, has two servo-controlled axes and one pneumatic axis. The supervisor computer tracks each car body through the painting booth and sends the correct path data to each machine controller at the proper time. A body-recognition system identifies each body as it enters the painting booth. The recorded information is sent to the supervisor computer and is checked against the plant schedule to determine the car's color and other options. In order to "teach" the painter a new routine a worker in the off-line teaching booth grasps a handle attached to the end of the teaching painter's arm and leads the spray guns through the appropriate paint paths, recording positions along the way and signaling "on" and "off" points. The resulting data are then stored in the system's computer.

their work. In my opinion they exaggerate. The scope for decision making by workers on the factory floor or in the large office is severely limited. An extreme division of labor results, as Smith perceived, in routine, repetitive tasks from which decision-making functions have been extracted.

Although American trade unions may have been too confrontational in their attitudes, their underlying conviction is that, beyond pressuring management to make the work environment safer, cleaner and more attractive, there is not much management can do to improve the intrinsic rewards from work. Accordingly unions have pressed and will continue to press for improvements in extrinsic rewards: job security, equity in selection for promotions, participation by the unions in discipline and discharge, better wages and fringe benefits, and more free time.

As my colleagues Ivar Berg, Marcia Freedman and Michael Freeman have documented in their book *Managers and Work Reform,* much of the agitation of the U.S. economy is a function of the expectations workers have about their jobs; there is a real danger that many are overeducated for the work to which they are assigned. Furthermore, much of the dissatisfaction of workers stems not from their limited scope to participate in decisions that affect their work but from their frustration with managers who fail to perform effectively.

Much of the preceding discussion of the workplace, worker motivation and the quality of work life has been in terms of the modern factory. Since the labor force is now overwhelmingly employed in the service sector, however, it seems desirable to call attention to a few future developments in the relation of mechanization to the work environment there.

Because of the critical importance of quality in the service sector the control of work and workers confronts management with a new and difficult challenge. Service-sector work has more dimensions and complexities than factory work, particularly considering the much higher proportion of professional, scientific and technical people employed in service industries. It is the hallmark of such personnel that their training has conditioned them to decide what work to do, how to do it and even when to do it. The members of a university faculty, although they are members of a department, a school and a larger institution, consider themselves as self-directed, autonomous individuals to whom the chairman, the dean and the president can address requests but not give orders. Increasingly this academic model is spreading to industry and government, to the research laboratories, to corporate staffs and to government agencies. There is growing tension between the traditional hierarchical structure of organizations and the implicit (and increasingly explicit) demands of professionals for greater autonomy in their work. How these demands will be reconciled with traditional modes of management remains to be seen, and the process of reconciliation may prove as difficult as it is important.

At the other end of the occupational scale it appears that the increase in the number of service-sector jobs has been correlated with the decrease in the fraction of the work force that is unionized. Many observers believe trade unions will be further weakened as the growth of the service sector continues. This may in fact happen, but several countervailing factors must be considered. Many service jobs pay low wages and provide limited benefits. More women, concentrated in low-paying service jobs, are becoming regularly attached to the work force. The computer revolution seems ready to make major inroads into the office, a development that holds a threat to the job security of many white-collar workers. The continuing erosion of the real earnings of workers by inflation makes these employees receptive to union organization. It is easy to write off the trade-union movement, particularly since it has had a conspicuous lack of success so far in restructuring itself to meet the challenges of a changing economy. Even if the unions finally succeed in making sizable gains in the service sector, they will face not only the conventional challenges of achieving higher wages and better fringe benefits for their members but also the challenge of contributing to a more stimulating workplace.

Veblen once explained the success of Germany in overtaking Britain as an industrial power in terms of the advantages of being second (or third). The latecomer did not have to carry the burden of obsolescent machinery or business practices. Many analysts in the U.S. in 1982 think Japan and the leading nations of the Third World have the same advantages Germany once had. The analogy is suggestive, but it is faulty. For some years various manufacturing activities have been moving to low-wage countries not only out of Western Europe and the U.S. but also out of Japan.

There is widespread concern about the periodic imbalances of U.S. trade in commodities with the rest of the world. In 1980 the deficit in such trade amounted to slightly more than $25 billion. That is not the whole story, however. Fees and royalties on direct U.S. investments abroad amounted to almost $6.7 billion, and net earnings on foreign investments, excluding these fees, came to $32.8 billion, resulting in a net surplus of more than $13 billion in goods and services (adjusting for the small net deficit in travel receipts). Goods and services do not lead totally independent existences, and as I have noted, services have come to play a much more important role in the production of goods. The challenge to the U.S. economy is not "reindustrialization" but rather "revitalization," in which mechanization has an important role to play with respect to both goods and services.

It is moot whether any new specific policies are required to speed revitalization beyond a recognition that the U.S. economy is moving ever more strongly into services and that the country's legislators and administrators should deal equitably between the different sectors in the creation and implementation of trade, tax and employment policies. The Reagan Administration, through the Office of the Special Representative for Trade Negotiations, has demonstrated a growing concern with international trade involving services. In the private sector a recently established consortium of major service companies is further evidence of attention and action.

A conclusion that government should not venture into the formulation of industrial policy does not imply that the state has no role to play in the strengthening of the industrial infrastructure. It is important to remember that government has played a major role in leading American industries: in agriculture, aeronautics, nuclear power, electronics, computers, communications, genetic engineering and other emerging technologies. If the present Administration has its way, the support of universities, the education and training of specialists and the underwriting of research and development will not be carried forward at an appropriate scale or with the adequate lead times. The machines that are invented, improved and put into operation throughout the economy depend on a steady accretion in the pool of knowledge and on the availability of enough technicians. If the country had to wait for the big corporations to train their own technical personnel from the ground up, it could wait a long time. Even if they wanted to do it, they could not. The ideologues may swoon over the beatitudes of the competitive market, which clearly has much to commend it, but the U.S. economy, for better or worse, is a pluralistic system in which government, nonprofit institutions and privately owned companies have complementary relations. No one of them, left to its own devices, can prosper in a technologically sophisticated world.

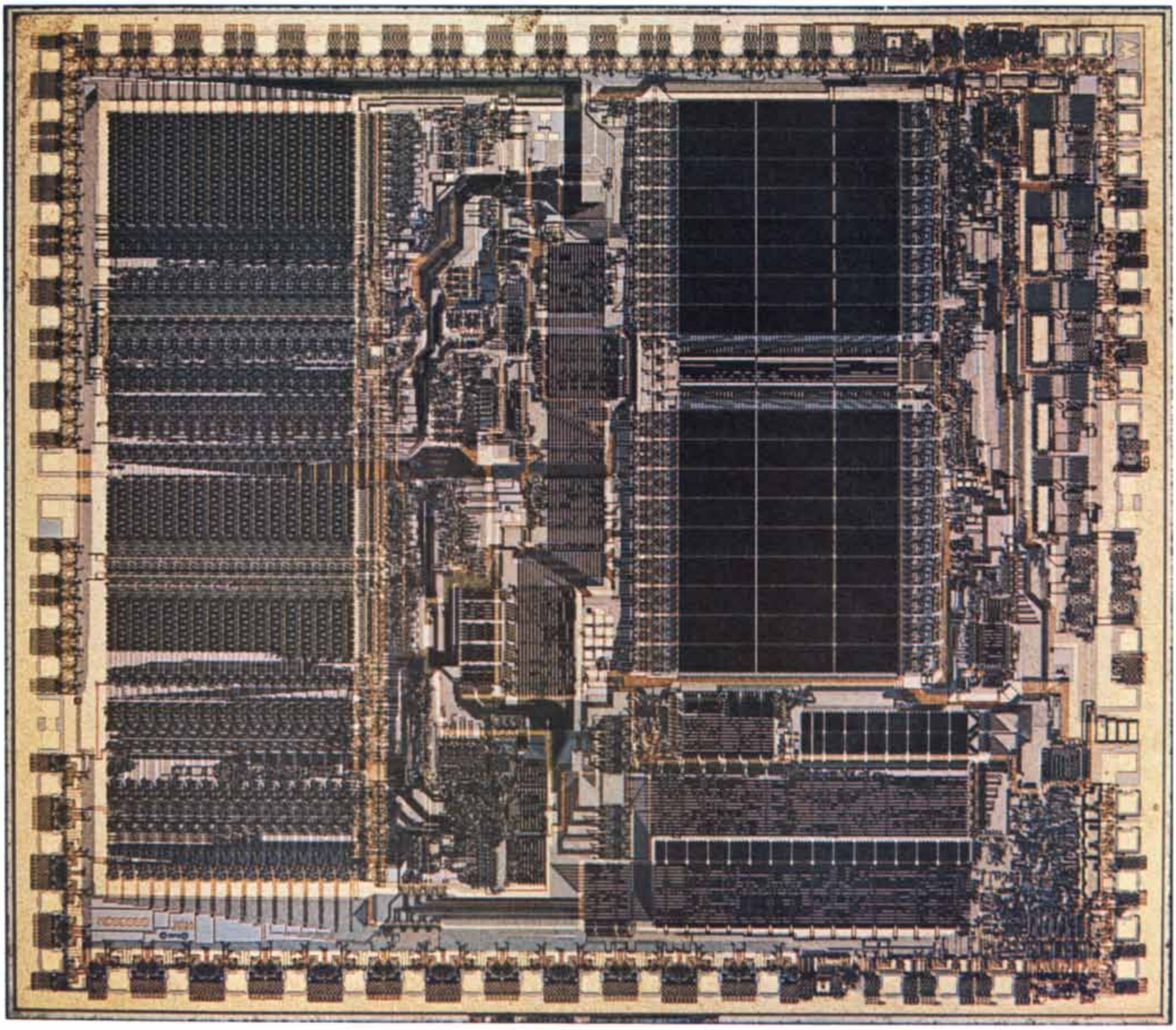
It would be a distortion to end this introduction to a series of articles on the mechanization of work without consideration of its problematical consequences. I shall therefore take up some of the consequences of mechanization for women and for the undereducated.

With respect to women, mechanization unquestionably paved the way for many of them to escape the confines of the home as a result of laborsaving devices, which eased the chores of housekeeping and, equally important, reduced the role of physical strength as a qualifying characteristic for many jobs. The positive role of mechanization in the liberation of women had little or no influence, however, on such untoward trends as the ominous rise in the number of households headed by women, the disturbingly large number of youngsters being brought up solely by their mothers and the large fraction of those families that live at or below the poverty level. These trends can be disregarded only by a society that is indifferent to human deprivation and unconcerned about its own future.

Before the introduction of sophisticated machinery as well as afterward all economies have faced difficulties in providing jobs for everyone who needs work. In spite of the good record of the U.S. economy with respect to the creation of jobs in recent decades Arthur F. Burns, the former chairman of the Board of Governors of the Federal Reserve System (and the current U.S. ambassador to West Germany), recommended in 1975, in the face of the continuing difficulties that many young people were having in finding and keeping jobs, that the Federal Government become "the employer of last resort" at wages 10 percent below the legal minimum wage. Some believe the shift of the economy toward services is currently making it more difficult for the undereducated to find a niche. An increasingly white-collar economy has no place for functional illiterates.

I have one concluding observation about the relation between mechanization and work. There is a widespread belief in the U.S. and Western Europe that young people have a smaller commitment to work and a career than their parents and grandparents had and that the source of the change lies in the collapse of the "work ethic." The question of why the work ethic collapsed is seldom raised, although sophisticated analysts suggest it is linked to economic affluence and the shift of concern from the family to the self.

I would suggest that the success of modern technology, which has put each of the superpowers in a position to destroy the other (and much of the rest of the world), presents a basic challenge, not only with respect to work but also with respect to all human values. It remains to be seen whether or not the potential of modern technology will turn out to be a blessing. Many young people are betting against such an outcome, and others are waiting before committing their modest stake.



MICROPROCESSOR at the heart of the graphics computer shown in the painting on the cover crowds some 70,000 transistor sites onto a single chip of silicon measuring roughly a fourth of an inch on a side. The chip, designated the MC68000, is the first in a projected family of integrated 16-bit microprocessors developed by Motorola, Inc. The dark areas at upper right are the system's memory elements.

The Mechanization of Agriculture

In the U.S. at the beginning of the 19th century some 70 percent of the labor force worked on the farm. Today 3 percent not only feeds the population but also produces a large surplus for export

by Wayne D. Rasmussen

Agriculture was once the primary means of livelihood for virtually all of the human population. As recently as 1850 farmers made up 64 percent of the labor force in the U.S. Today, in contrast, only 3.1 percent of American workers are engaged in agriculture, yet they grow enough to meet the needs of the entire country, often with a large surplus for export. In 1850 the average farm worker supplied food and fiber for four people; now each farmer provides for 78 people.

Much of the enormous increase in productivity can be attributed to mechanization, broadly defined. In agriculture mechanization can be taken to include not only the introduction of devices such as plows and reapers but also the development of improved crop plants, fertilizers and pesticides, the construction of irrigation works, the growth of a transportation network for the distribution of farm produce and the extension of electric power to rural areas. These technological innovations have profoundly altered the economic and social basis of life on the farm. Indeed, the magnitude of the demographic change suggests that agriculture may be the realm where the mechanization of human work has so far had the greatest effect.

The introduction of agriculture itself, perhaps 10,000 years ago, transformed human society, and the history of farm mechanization might well be traced back to that era. In this article, however, I shall confine my attention to the past 200 years or so. Moreover, I shall consider only the mechanization of farming practices for the major crops grown in the U.S.

Land for farming has always been plentiful in the U.S., at least until now, and cheaper than labor. Hence almost any device that makes it possible to work more land with the same amount of labor has been welcomed.

At the time of the American Revolution most of the tools employed on the farm differed little from the ones that had been in use for 2,000 years. Grain was cut almost universally with a sickle, a tool that required the laborer to work in a stooped position. It was not until about the time of the Revolution that the scythe came into use; its long blade enabled the worker to cut more with one swing and its long handle enabled him to work standing up. The next improvement was the cradle, a wood frame attached to the blade of the scythe. The cradle caught the grain or hay so that it could be laid down in even rows, making it easier to gather.

With the agrarian emphasis of the 18th-century economy it is no surprise that various prominent men (many of whom had extensive agricultural holdings) were looking for new implements and more productive ways of farming. George Washington asked Arthur Young, a British advocate of agricultural change, to get improved farm implements for him. Thomas Jefferson turned his inventive mind to the improvement of farm tools and developed designs for a seed drill, a brake for separating the fibers of hemp, a threshing machine, a sidehill plow and a moldboard (the curved part of a plow blade) that would turn the soil efficiently.

The best-known advance in farm production in the years immediately after the Revolution was the invention of the cotton gin. Upland cotton, the type grown then and now in the South, has fibers that cling to the seed. Extracting the seeds had been tedious and labor-intensive work. The gin (or engine) invented by Eli Whitney in 1793 gave farmers a practical machine for separating the lint from the seeds and brought about a dramatic change in Southern agriculture. The production of cotton rose from an estimated 10,500 bales in 1793 to nearly 4.5 million in 1861. The extensive commercial production of cotton led to the expansion of the plantation system and an intensification of the system's reliance on slave labor. In this instance, then, mechanization (at least in its earliest stages) certainly did not relieve the drudgery of the worker, nor did it lead to his disemployment; on the contrary, it perpetuated the most exploitative labor practices.

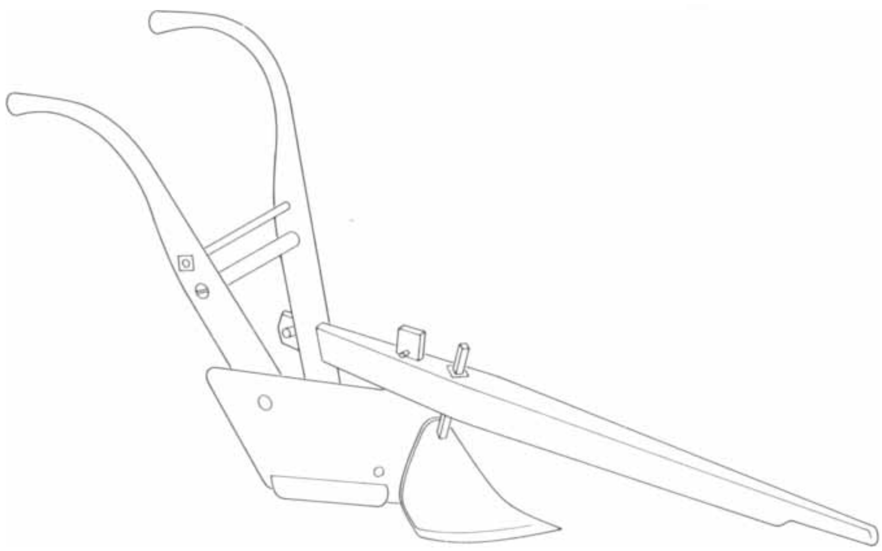
In New England the availability of low-cost cotton and of the new spinning and weaving machinery developed in Britain led to the rapid industrialization of the economy. The demands of the mill towns offered farmers in New England and elsewhere an expanding market for their products, providing a stimulus to experimentation with new implements and methods. Here the economic and social effects of mechanization in agriculture began to have a direct influence on other sectors of the economy. The increased agricultural production ensured a steady supply of food at a reasonable cost to the mill workers, thus encouraging industrial development. The increased agricultural productivity meant that young people could leave the farms (indeed, they were almost forced to) for jobs in the mill towns, thereby providing industry with relatively low-cost labor while relieving population pressure in rural areas.

In cotton farming the gin virtually abolished limits on the volume of production. In the growing of grain, on the other hand, there were many bottlenecks, which were resolved only through a series of inventions and improvements in machinery. The problems began with plowing and ended with reaping.

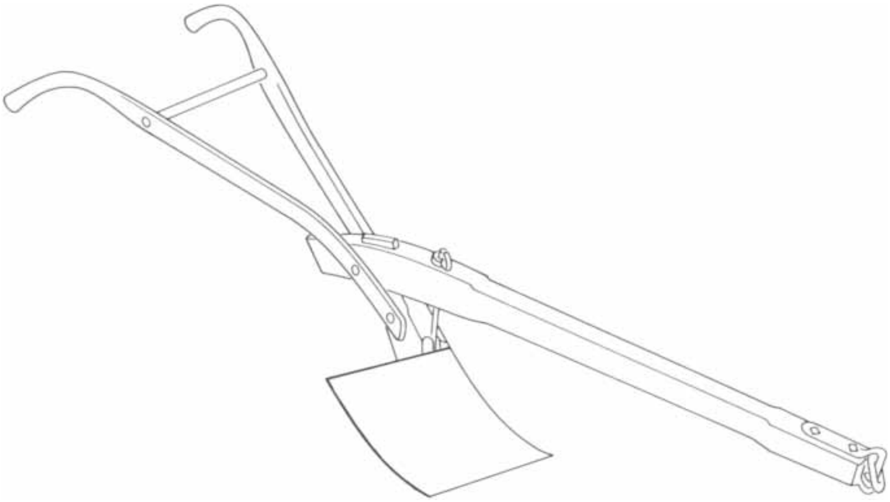
TREND TOWARD MECHANIZATION in agriculture is evident in the photograph on the opposite page, which shows a mobile packing plant for harvesting carrots on a large farm in California. The workers at the right pull the plants and remove the tops, putting the carrots on a conveyor that takes them to a cleaning unit, where dirt and root hairs are removed, and through a washer. The workers at the left sort the carrots, putting the smaller ones in one-pound bags for retail sale and the larger ones in big fiber bags for sale to restaurants and institutions.

Plowing drew the attention of many inventors. The first U.S. patent issued for a plow went to Charles Newbold of New Jersey in 1797. His plow was a single piece of cast iron except for the handles and the beam by which it was hitched to the draft animals. It is said that farmers would not buy the plow in the belief the iron would poison the soil and make weeds grow. In 1814 Jethro Wood patented another cast-iron plow, which he improved in 1819; the moldboard, the share (the part that cuts the furrow) and the landside (which guides the plow along the furrow) were cast separately, and the three parts were interchangeable from one plow to another. Wood's plow was widely adopted.

Neither wood nor cast-iron plows worked well in the sticky soil of the prairies, which were to become the heartland of American grain farming. The soil stuck to the plow instead of sliding by and turning over. In 1833 John Lane, a blacksmith in Lockport, Ill., began fastening strips of steel of the kind meant for saw blades over wood moldboards. His plows turned furrows in the prairie loam of Illinois, but he did not patent his idea. In 1837 John Deere, who was also a blacksmith in Illinois, began making plows out of saw steel and smooth wrought iron. The plows were highly effective in the prairie soil, and Deere, in partnership with Leonard Andrus, soon built up a substantial business.



EVOLUTION OF THE PLOW in the U.S. over the past 200 years is traced in the illustrations on this page and the opposite page. This horse- or ox-drawn plow, which is typical of the kind used in the 18th century, was made out of wood except for the pointed share at the front.



PRAIRIE PLOW was invented by John Deere in 1837 to cope with a problem that had arisen as agriculture expanded into the prairies of the Middle West: the soil stuck to the wood and cast-iron plows employed at the time instead of sliding by and turning over. Deere made his plow blade of saw steel and smooth wrought iron; it functioned well in the sticky prairie soil.

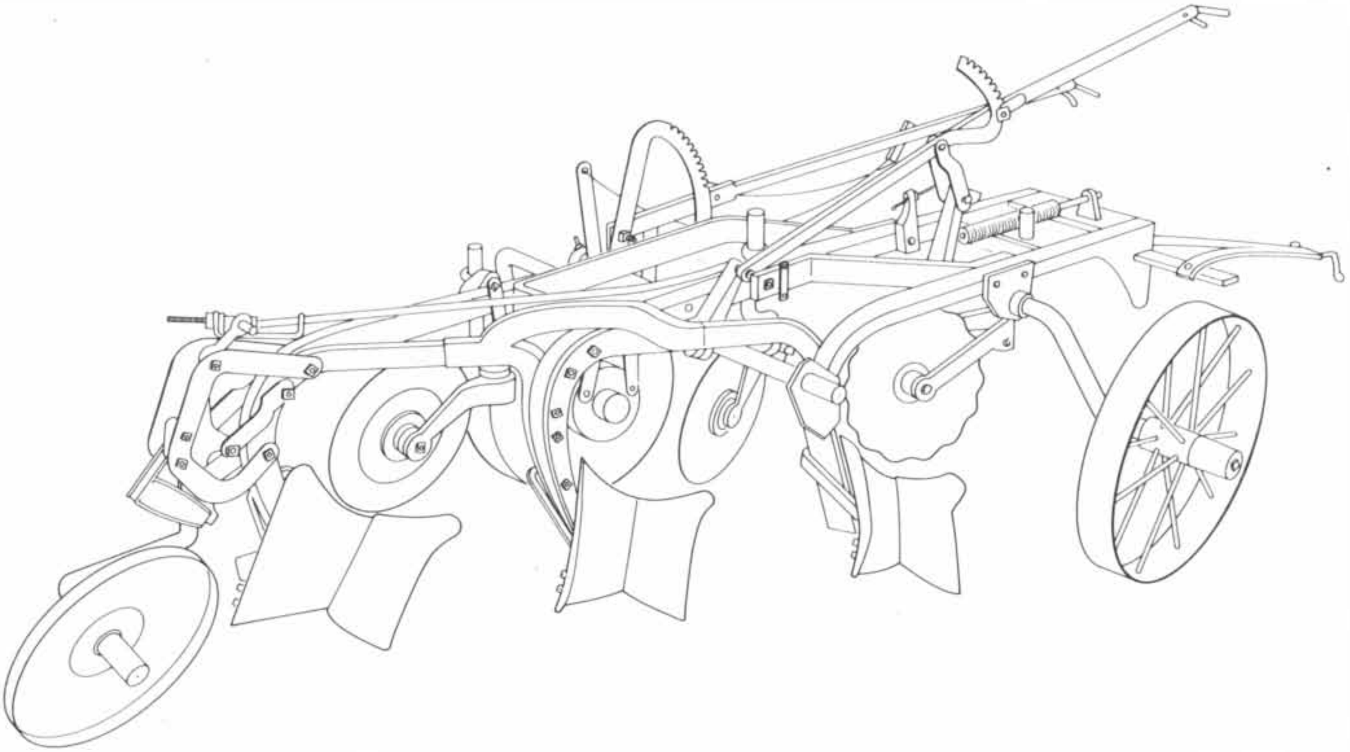
Harvesting was the crucial operation in the production of grain. Hence the mechanical reaper was probably the most important invention introduced into farming between 1830 and 1860. Obed Hussey of Maryland patented a practical horse-drawn reaper in 1833. Cyrus H. McCormick of Virginia had devised a similar machine by 1831, continuing work along lines begun by his father, and he patented it in 1834. Over the next 20 years McCormick gained a dominant position in the business, partly because he moved his company to Chicago, where he could better reach customers in the newly opened prairies and plains, whereas Hussey kept his plant in Baltimore.

By 1851 McCormick was producing 1,000 reapers a year in his Chicago plant. Over the years the harvester was improved in various ways. One notable improvement was the twine knotter, which was perfected by John F. Appleby in 1878. It enabled the machine to tie the cut grain into bundles for quicker and easier handling.

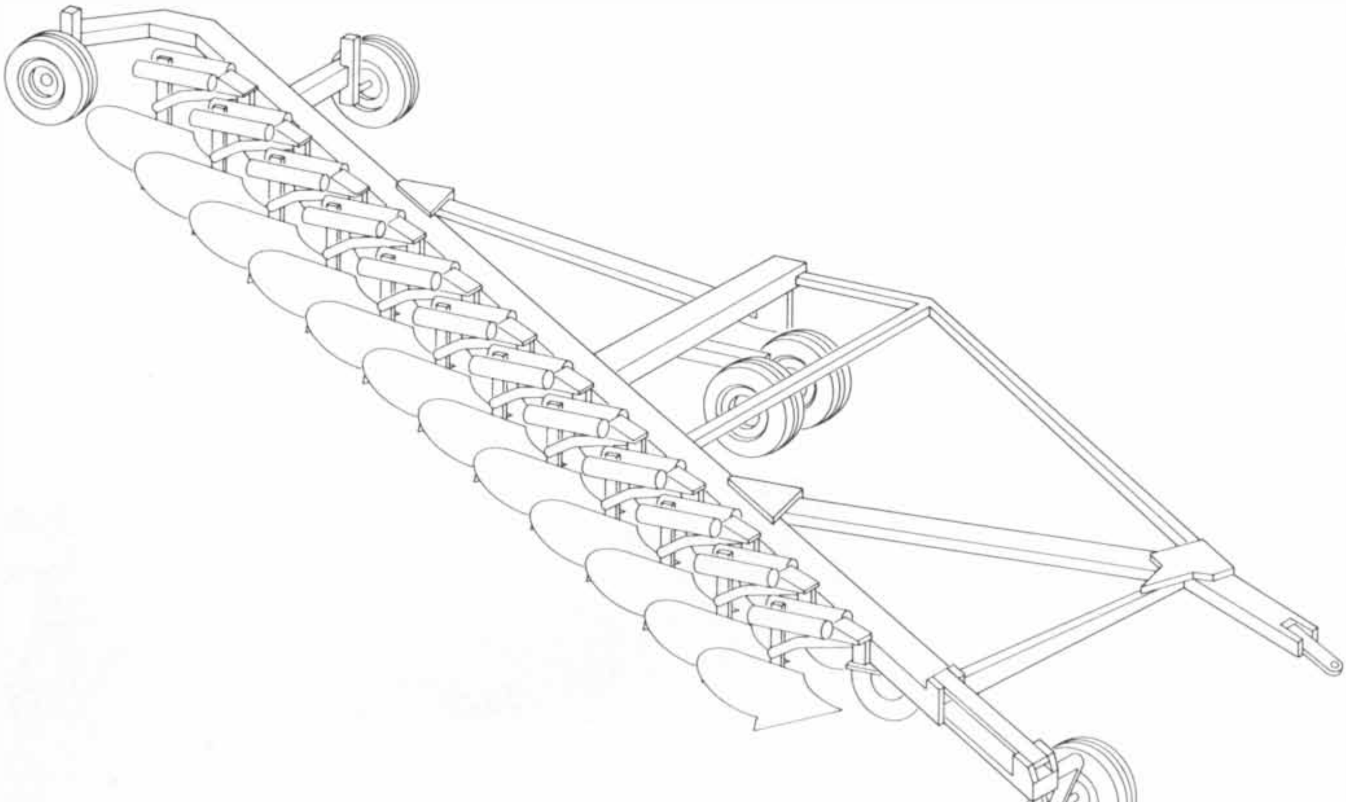
The success of the reaper and other horse-powered devices (including some developed earlier than the reaper) encouraged a trend toward machines that did not depend on human muscle power. A corn cultivator and a hay and grain rake, both drawn by horses, were available by the 1820's. In 1837 John A. Pitts and Hiram A. Pitts patented a commercially successful threshing machine. A mower that gained wide acceptance was patented by W. F. Ketchum in 1844. Other horse-powered machines marketed before the Civil War included grain drills, corn shellers, hay-baling presses and cultivators of various types.

In spite of these advances, which were publicized and advertised in the agricultural magazines of the 1840's and 1850's, many farmers hesitated to invest in the new machinery until they could be certain the investment would pay off. It was the Civil War that ultimately provided the impetus for change, and the subsequent conversion from hand power to horsepower can be designated the first American agricultural revolution. The progress of the revolution is recorded in the statistics on investment: in constant-value dollars the average annual investment per farmer in new machinery and equipment was $7 in 1850, $11 in 1860, $20 in 1870 and $26 in 1880. The labor shortage brought on by the war, together with high prices and a seemingly limitless demand, encouraged farmers to spend their savings or to go into debt to acquire the labor-saving machines. Once the farmer had made the investment he found himself committed to production on a commercial scale.

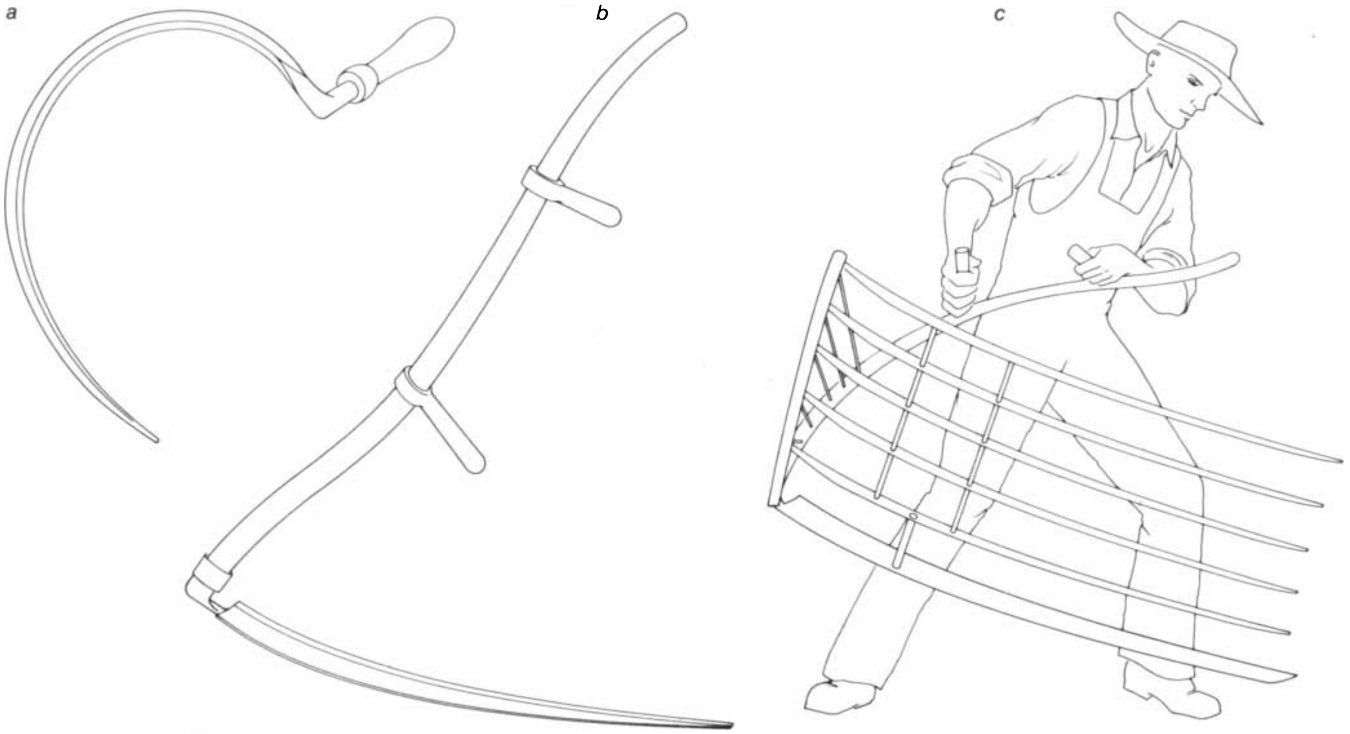
From 1820 to 1850 there had been virtually no change in the productivity



TRACTOR PLOW of the type that was common in the 1920's represents an early stage in the transition from similar horse-drawn apparatus. In the horse-drawn version the plow had a seat for the farmer. Many horse-drawn plows continued in use until after World War II.



MODERN GANG PLOW has 12 blades, and each blade is capable of making a 22-inch cut. When the device is drawn by a tractor on level, open ground, it can plow 10 acres per hour or more. Deere & Company makes this plow and others with from 10 to 16 blades.

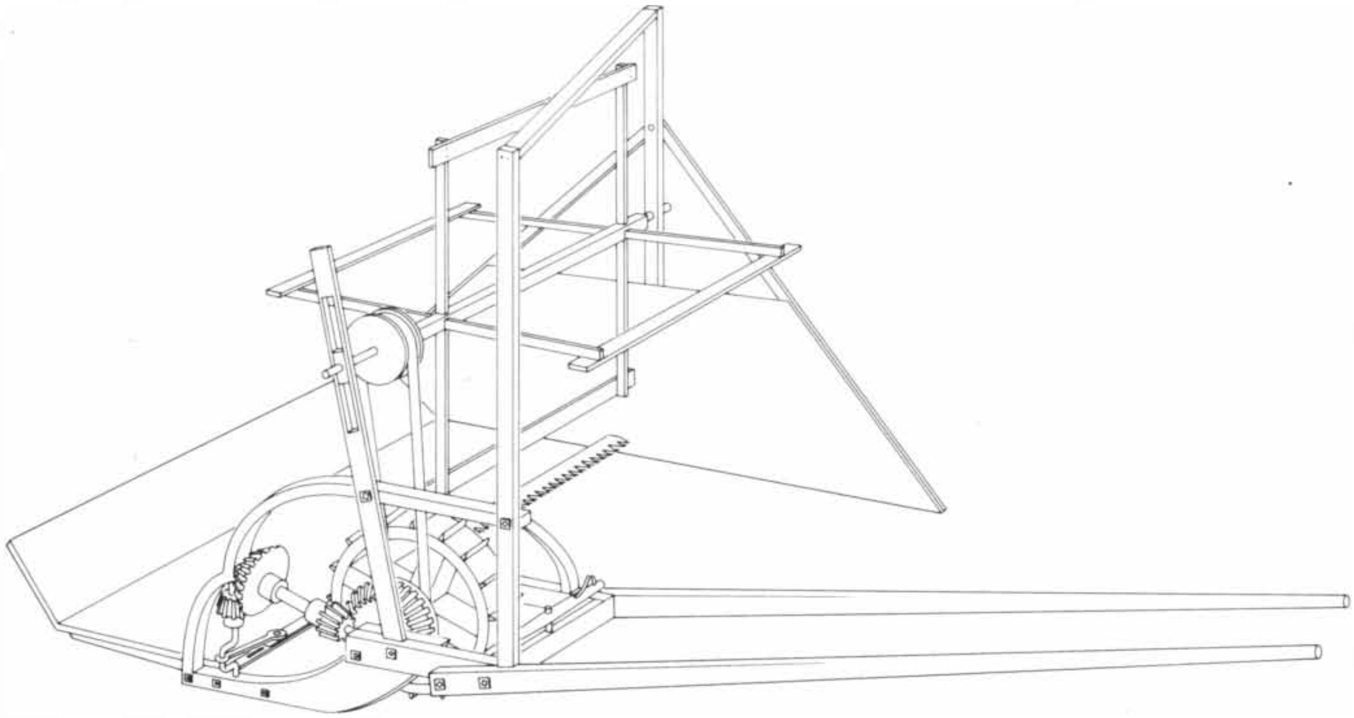


EARLY REAPING TOOLS were in use in the U.S. until well into the 19th century. The sickle (*a*) required the harvester to cut grain or grass in a stooped position; the scythe (*b*), developed at about the time of the American Revolution, enabled him to work standing up and to cut more with each stroke. The cradle (*c*) was the most advanced harvesting implement known to farmers of the early 19th century. It was a scythe with a wood frame attached. With it the harvester could catch the cut grain or hay and lay it down in even rows.

of the farm worker. In the following 30 years, however, production per man-year increased markedly, even though the average yield per acre improved little. The number of people who could be supplied with food and fiber by one farm worker rose from four in 1850 to five and a half in 1880. The number of farmers continued to increase, but at a rate lower than that of the general population. As a result farm workers as a proportion of the U.S. labor force decreased from 64 percent in 1850 to 49 percent in 1880.

The technological changes also had social repercussions. The capital needed to establish a farm increased, making it harder for laborers, tenants and young people to become operators of farms. Farmers became more dependent on bankers and merchants. Except during

THRESHING OPERATION in Kansas in 1909 was done with steam-powered machinery but still required a considerable work force. The steam tractor at the right, with a coal-carrying trailer attached to it, delivered power to the separator by means of the long



MECHANICAL REAPER was patented in 1834 by Cyrus H. McCormick. It was not the first reaping machine, but it soon became the dominant one. In this one-horse model the large ground wheel transmitted power to the reciprocating cutter blade by means of gears and a crank and to the revolving reel by means of a belt. The reel gently pushed the grain onto the platform at the rear. The grain was then raked onto the ground by hand and formed into small sheaves that were picked up and gathered into shocks to dry before threshing.

the war years the higher production of agricultural goods led to periods of surplus and low prices. Farmers were advised to reduce production, but no one farmer could influence the market. Furthermore, it was necessary to bring more land under cultivation in order to pay for the very machines that made this expansion of agriculture possible. For at least some farmers mechanization undoubtedly brought release from toil and a measure of prosperity, with the associated benefits of more leisure and better education. To some extent, however, it seems the agricultural bounty of the late 19th century was secured at the expense of the farmer.

The Homestead Act of 1862, which made Western land available free to settlers, and the building of the transcontinental railroads encouraged established

belt. The separator removed the grain from the stalks. Five horses (of the 10 or so needed in the operation) and 13 men can be seen. Most of the men worked with pitchforks, moving shocks of cut grain onto wagons in the field and then pitching the grain into the separator.

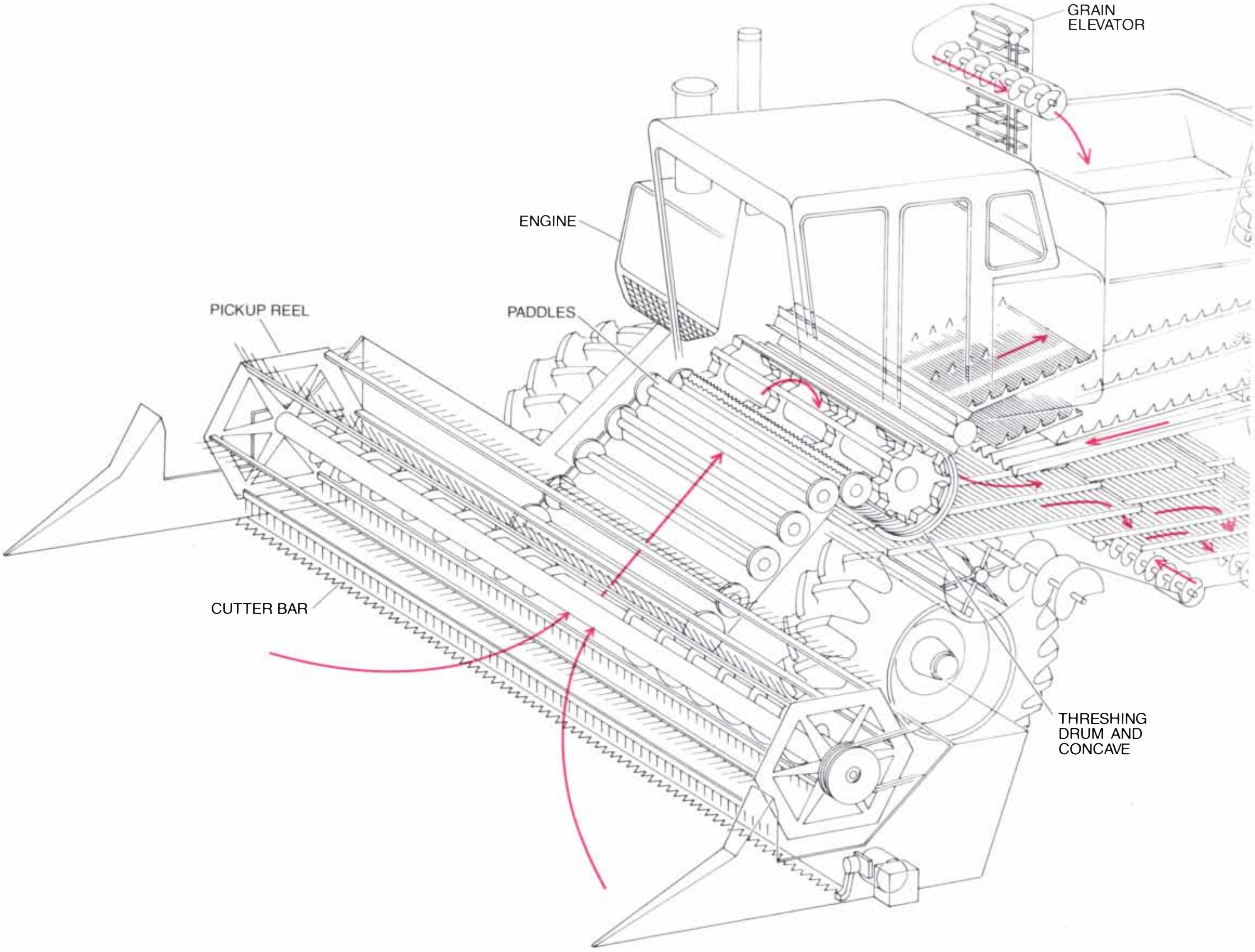
farmers and immigrants from Europe to go west, opening up the plains first to cattle and then to wheat. On the newly cultivated land machines became increasingly important. And even as the horse became fully established as the prime mover of agriculture, new sources of power were developed. Steam engines, first stationary and then self-propelled, were applied in many operations on large farms, particularly in the West.

The Red River Valley in North Dakota and Minnesota provides an impressive example of large-scale farming based mainly on steam power. When the Northern Pacific Railroad suspended its construction of new lines in the major economic depression that began in 1873, some of the officials of the company accepted land in the Red River Valley in exchange for their railroad bonds. In 1875 Oliver Dalrymple, an experienced wheat farmer in Minnesota, contracted to manage the land. He began raising wheat on tracts so large that some of the plowed furrows were six miles long. Although horses and mules supplied much of the power, Dalrymple put his emphasis on steam tractors, which he hitched to the most modern machinery available.

Dalrymple's venture provided an early demonstration of the problems that can beset a large mechanized farm operation: breakdowns of machinery, the unreliability of labor, variations in climate and low prices for farm products. The same problems affected smaller, family-operated farms, but the family farm had more opportunity to reduce or defer expenditures because the family did not have to meet a payroll for hired labor or show a profit for the owners. By the 1890's most of the large, single-crop farms had given way to smaller, diversified holdings.

In general the task for which steam engines proved to be most useful was threshing grain. The engines were too heavy and cumbersome for most other farm work. The peak in the manufacture of steam engines for agriculture came in 1913, when 10,000 of them were made. Production declined rapidly thereafter as the gasoline-powered tractor began to dominate the market.

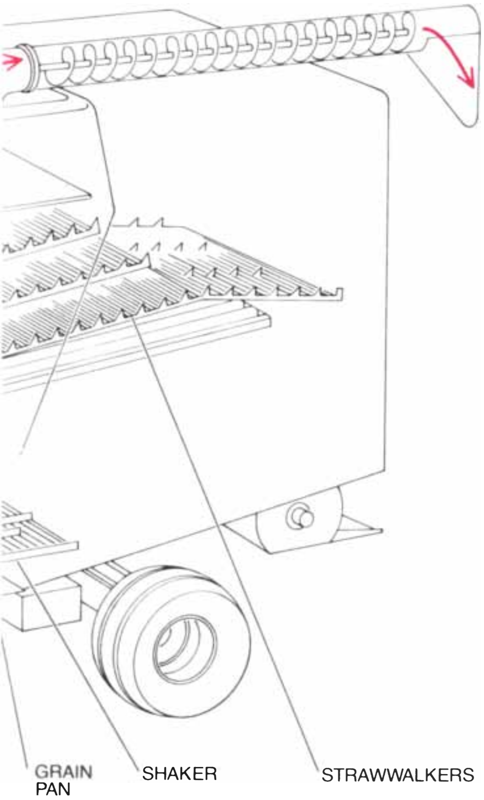
The first practical self-propelled gasoline tractor was built in 1892 by John Froelich of Iowa. He mounted a gasoline engine made in Cincinnati on running gear fitted with a traction arrangement of his own manufacture. With this machine he made a 50-day threshing run. The Froelich tractor was the forerunner of the Deere line of tractors.



MODERN COMBINE derives its name from the fact that it combines the operations of harvesting grain and threshing it. The grain is cut by the reciprocating cutter bar and picked up by the reel. Augers steer the grain stalk-first onto a moving elevator that carries it to the threshing drum, where it is stripped and beaten. Some grain drops into the grain pan. The straw and the rest of the grain go on to the strawwalkers, which shake back and forth and cause more grain to fall into the pan. The grain elevator empties into a bin that can hold about 180 bushels of grain until the auger at the rear unloads it into a truck. The straw drops off the walkers and onto the ground; the chaff

The first business concerned exclusively with the manufacture of tractors was established in Iowa City in 1905 by C. W. Hart and C. H. Parr. They had started working on internal-combustion engines after meeting as students at the University of Wisconsin in 1893. Their first tractor came out in 1901; it was crude, but it remained in service for 20 years. The Hart-Parr Company later became part of the Oliver Corporation. Many other tractor-making concerns (not all of them successful) were formed in succeeding decades.

The adoption of the gasoline tractor spread rather slowly until World War I. Then high prices for farm products, government appeals for increased production and labor shortages in some areas encouraged farmers to make the transition. After the war and a sharp drop in farm prices in July, 1920, the pace of conversion slackened again. Through the rest of the 1920's fluctuating economic conditions in agriculture made farmers reluctant to give up horse-drawn equipment for the tractor, which would entail additional outlays of cash. Nevertheless, the number of horses and mules on farms decreased steadily and the number of tractors increased.



is blown out at the rear by a fan. The entire operation is powered by a diesel engine. The "concave" fits around the threshing bars. This large combine, which can harvest 12 acres per hour, is made by Massey-Ferguson, Inc.

One machine that had come into its own by the 1920's was the combine, which cuts the grain and threshes it in a single operation. In the harvesting of wheat the combine replaced both the stationary threshing machine and the grain binder, which had mowed the wheat and bundled it into shocks. The first successful combine was a horse-powered machine built in 1836 in Michigan. By the 1880's steam engines had been introduced to power the many combines coming on the market. The gasoline engine began to replace steam for pulling the combine and operating its harvesting mechanisms in about 1912. Large combines powered by gasoline engines were widely available in the 1920's and 1930's. The development in 1935 of a one-man combine powered by a two-plow tractor (that is, a tractor with enough power to pull two plows) was another milestone.

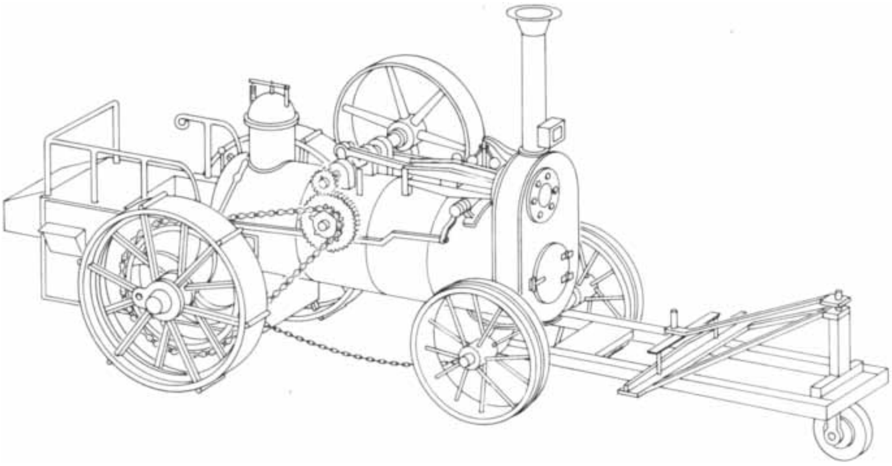
By 1956 more than a million combines were at work on American farms, and the 1.5 million grain binders that had been in use in the decade before World War II had virtually disappeared. Also gone was the substantial crew that had made threshing and the feeding of threshers the biggest and hardest jobs of the year on most grain farms. The threshing crew itself usually consisted of three men. The separator man was responsible for the operation of the machine that separated the grain from the straw and the chaff. The engine man ran the tractor, which powered the separator by means of a long belt. The steam tractor remained in service for threshing long after the gasoline tractor had become common for other work, and so the crew also had a water man to supply the steam tractor with water. If the threshing was done from shocks in the field, two or three more men were needed to pitch bundles of grain onto horse-drawn hayracks, each of which had a driver, and often another man or two men were needed to pitch bundles into the separator. The crew for a farm of medium size would run to about a dozen workers. Those who were not in the family and not living nearby could sleep in the barn, but they all had to be fed. Cooking for them was the ultimate test of the farm housewife.

World War II was the impetus for the virtually complete transition to mechanization. This was the second American agricultural revolution: the change from animal power to mechanical power. The war was not the only factor leading to change. In the 1930's the farm programs of the New Deal had enabled some farmers to replace worn-out machines with new models. The rural-electrification program had brought a major new source of power to many farms (and eventually to nearly all of them). With electricity farmers could run useful devices of all kinds, including not only electric lights but also milking machines, feed grinders and pumps. It took the war, however, and the accompanying shortages of farm labor, high prices for farm products and an enormous demand for those products to convince nearly all American farmers to turn to tractors and related machines.

In general American farmers have adopted a new technology on a large scale only when it has been developed and tested at a time of favorable economic conditions. The early inventions often began in the shops of farmer-mechanics, but the testing, improving and selling were done by the manufacturers of farm implements. Later on engineers at the land-grant universities and at the Department of Agriculture built the prototypes of new machines; again, however, the manufacturers did the testing, perfecting and distributing, as well as some of the inventing. The land-grant universities, the agricultural-experiment stations and the extension services have had another essential role: they have educated farmers in the advantages of the machinery and in the way farm work should be adjusted to exploit it fully.

New machines were only one aspect of the second agricultural revolution; mechanization and many other changes constituted a package of practices, or what has been called the systems approach to the improvement of agricultural productivity. The other changes included the controlled application of lime and fertilizer, soil-conservation techniques such as the planting of cover crops, irrigation where necessary, the creation of improved varieties of plants and breeds of animals, the adoption of hybrid corn, the formulation of more balanced feeds for livestock, the more effective control of insects and diseases and the use of chemical weed killers and defoliants. The effects of these practices on agricultural output were dramatic. In many respects rural life was affected just as profoundly because of the consolidation of farms and the sharp decline in the farm population.

The production of sugar beets is a good example of laborsaving through mechanization and the development of a new type of seed. Before World War II the sugar-beet farm had a few machines and specialized implements, including horse-drawn seed drills, cultivators, lifters (for pulling up the plants) and wagons, but hand operations dominated thinning in the spring and harvesting in



FARM LOCOMOTIVE ENGINE was one of the earliest steam tractors; it became available in about 1860. The railed area at the back is a fuel bunker. The one-wheel rig at the front is the steering apparatus; an operator sitting on the board seat turned the single wheel by means of the vertical handle in front of the seat, causing the front wheels of the tractor to turn. Another man ran the boiler. A third man was probably needed to keep the boiler supplied with water.

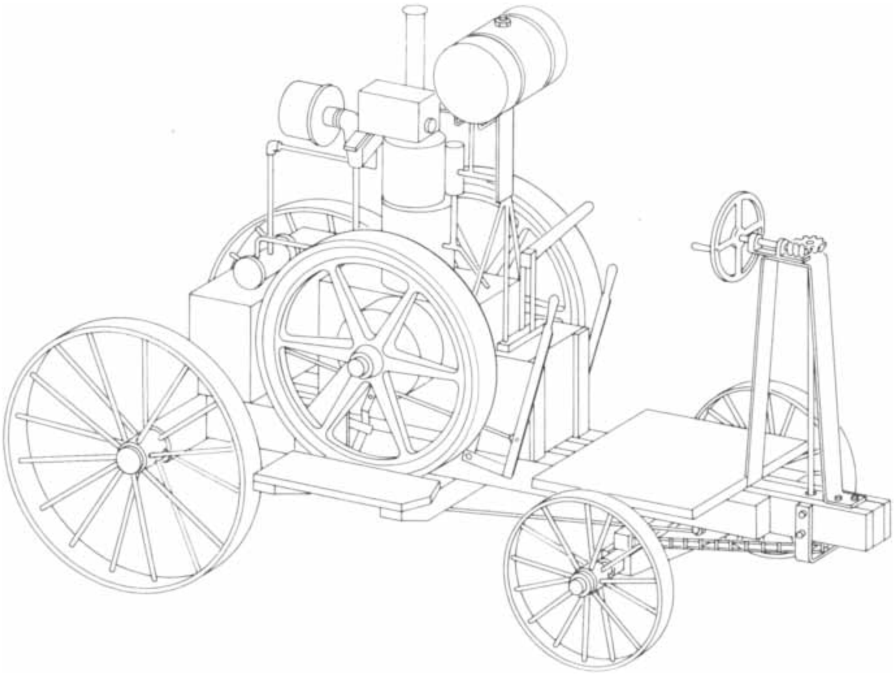
the fall. The work was generally done by migrant laborers. In the 1930's the California Agricultural Experiment Station at Davis and the Bureau of Agricultural Engineering of the Department of Agriculture began a cooperative research effort aimed at developing a combine for sugar-beet harvesting, that is, a machine that would lift the plants, remove the tops and load the beets in one pass down the row. Over a period of years several devices were developed to do one part of the job or another; the ideas were turned over to private manufacturers, who carried on the work. By 1958 two major types of harvester were being manufactured. In that year the entire sugar-beet crop was harvested mechanically, compared with only 7 percent in 1944.

The task of thinning out the weaker plants was tackled both mechanically and by modification of the seed. In 1941 some multigerm seeds, which ordinarily give rise to a cluster of several plants, were sheared into segments and planted; many of them produced only one plant, greatly diminishing the need for thinning. Sheared seeds were adopted by a number of growers. In 1954, however, a better solution was made available with the release to growers of the first monogerm seeds. Today, with the precision planting of monogerm seeds and the use of a mechanical thinner, the production of sugar beets in the U.S. is completely mechanized. The growers have become independent of migrant labor.

The migrant-labor problem was also back of the research leading to a mechanical tomato harvester. Much of the tomato crop in California had been picked by Mexican laborers who entered the U.S. under the terms of the Bracero program. When the program was ended in 1964, growers reported it was not possible to recruit U.S. citizens to do the work. Some labor leaders disputed this view, but the controversy was effectively ended by the successful mechanization of the harvest.

The application of machinery to tomato picking required the convergence of two lines of work, both carried on at the California Agricultural Experiment Station at Davis. One achievement was the breeding of a new variety of tomato plant by Gordie C. Hanna. With appropriate amounts of fertilizer and water the plants of this variety set an abundant crop of fruit, and all the fruit ripens at about the same time, so that an entire field can be harvested at once. Furthermore, the fruit can withstand machine handling.

The harvesting machine itself was devised by Coby Lorenzen, Jr. It cuts the plants at ground level, lifts them into a compartment and removes the fruit by shaking the vines. A belt then carries the tomatoes past a crew riding on the machine, who remove green fruit and clods of dirt. The first tomato harvesters had a capacity of from eight to 12 tons per hour. A total crew of 12 handled about the same amount of fruit that could be harvested by 60 people picking manually. In 1963 only 1.5 percent of the tomatoes grown in California for processing were harvested by machine; by 1968 the fraction was 95 percent, and now it is virtually 100 percent. Moreover, the crew on the machine has been reduced to three or four.



FROELICH TRACTOR, made by John Froelich of Iowa in 1892, was the first practical self-propelled gasoline tractor. It was also the first to propel itself both forward and backward.

The mechanization of cotton harvesting has affected even more people. The first device, the cotton stripper, removed the bolls from the plant. It came into wide use in Texas in 1926 but was reasonably satisfactory only in certain areas. In 1928 John D. Rust and Mack D. Rust of Texas patented a spindle picker, which pulled the cotton fibers from the boll by wrapping them around spindles. The spindle picker gained acceptance slowly until World War II, when high demand and high prices for cotton stimulated manufacturers to build more machines. Even so, less than 10 percent of the cotton crop was harvested by machine in 1949. By 1969, however, the fraction was at least 96 percent. In the same period improvements in land preparation, planting techniques, the application of fertilizers and the control of water, weeds and pests increased the average yield of upland cotton from about 300 pounds of lint per acre to more than 500. Most of the drudgery had been eliminated from cotton farming. In 1945 about 42 man-hours were needed to produce 100 pounds of cotton in the U.S., but by 1975 the same output was being achieved in only two-thirds of a man-hour.

The sharp gain in productivity has reduced by several hundred thousand the number of workers needed on American cotton farms. One effect of the diminished need for manpower has been the virtual end of sharecropping, which had long been considered detrimental to the sharecroppers, the owners and the land. Those farmers who continue to raise cotton have benefited from a rise in the rural standard of living and from a lessening of racial discrimination. On the other hand, many of the displaced sharecroppers and laborers have found few opportunities for alternative employment.

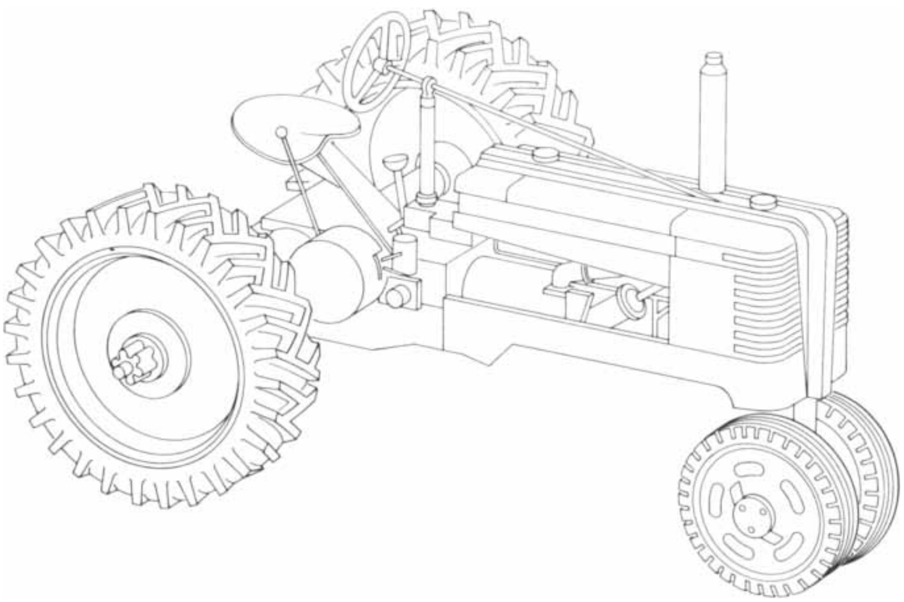
Not long after they had invented the spindle picker the Rust brothers recognized that the machine could put "75 percent of the labor population out of employment." They were unwilling to see that happen and resorted to one plan after another to prevent it. Their ideas included adapting the machine to small farms, marketing it with restrictions on how it could be deployed, selling it only to community farming projects organized as cooperatives and setting apart some of their profits to assist displaced cotton farmers. None of the schemes proved practical, however, and all of them were swept aside when the effects of World War II brought several more companies into the business of manufacturing cotton harvesters.

Another agricultural technology that has changed greatly in the past few decades is irrigation. A person flying from east to west across the U.S. can see, beginning at the line of 100 degrees longitude or just beyond it, one circular field after another, extending from Texas to North Dakota. The circles result from one of the newest developments in irrigation: the center-pivot sprinkler, an almost totally automatic system. The sprinkler is a long pipe with nozzles at intervals along its length; the pipe is mounted on wheels and pivots around the center of the field, tracing out a circular area over the crop plants. The system is propelled by water turbines or electric motors. One center-pivot sprinkler irrigates a circular area of about 133 acres.

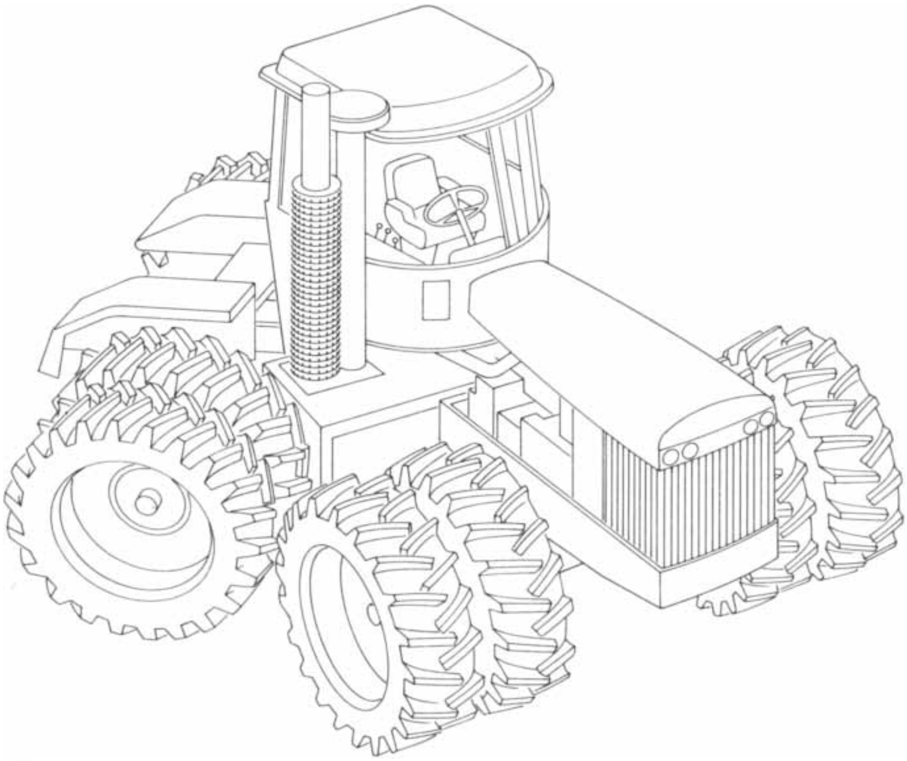
The center-pivot system is far removed from the ditch built by the first Mormon pioneers in Utah to divert water from City Creek to their fields. This first instance of modern irrigation agriculture was based on early irrigation systems developed by the Indians of the Southwest long before the arrival of Europeans. Mormon settlers moving from Utah into parts of Arizona, Colorado, Idaho, Nevada and New Mexico took their cooperative irrigation practices with them. The technology was soon adopted throughout the West. Streams were dammed and the stored water was carried by ditches to leveled land to increase productivity far beyond what was possible with natural rainfall.

The streams and the amount of water available were severely limited in most parts of the West. In addition irrigating with surface water moved by gravity was a task demanding many hours of heavy labor as the irrigator attempted to control the movement of the water over his fields. After World War II the use of movable aluminum pipes aided in this task. The supply of water has been augmented in many parts of the West, notably in Texas and Nebraska, by massive pumping from relatively shallow wells reaching supplies of ground water built up over hundreds of years. The water is usually distributed over the land by some type of sprinkler system, of which the center pivot has proved to be one of the most efficient. The prototype of this device was built in 1949 by Frank Zybach, a Colorado tenant wheat farmer.

The major disadvantage of the center-pivot system drawing on well water in the arid West is that the supply of under-



EVOLUTION OF THE TRACTOR is shown by this model of the 1930's. The front wheels were spaced to pass between two rows of plants and the rear wheels to straddle the rows.



MODERN TRACTORS are exemplified by this four-wheel-drive Deere model, which can develop almost 300 horsepower at an engine speed of 2,100 revolutions per minute. The tractor is articulated: it turns by bending at a center hinge while the wheels remain parallel to the frame. With this arrangement the rear wheels always follow the same path as the front ones.

ground water is limited. Indeed, in some parts of Texas farmers have exhausted the supply and can no longer irrigate their lands. In an attempt to conserve steadily decreasing supplies of available water suitable for irrigation some farmers are turning to "trickle" or "drip" irrigation. Instead of sprinkling or moving the water in open ditches over the surface of the field, pipes deliver small quantities of water directly to the plants. The system is expensive to install, but it reduces evaporation and also cuts sharply the amount of labor needed for irrigation.

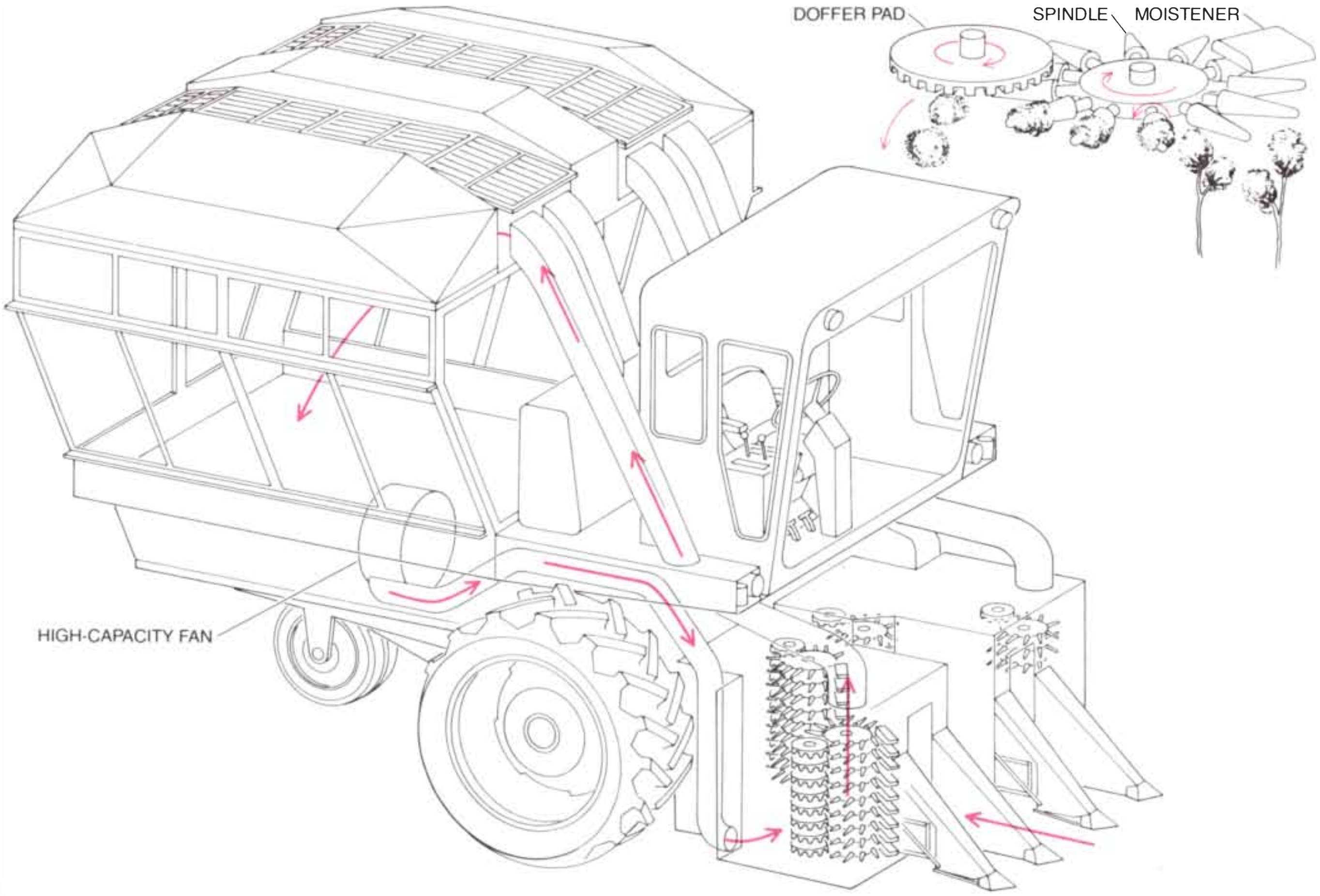
The second American agricultural revolution also saw mechanization and related practices extended to animal husbandry, particularly in the production of eggs and broilers, milk, hogs and cattle. Poultry production had led the way earlier, with the development of practical incubators and brooders in the 1870's. The incubators replaced the hen in providing constant warmth to the eggs until they hatched and the brooder provided warmth and shelter for the chicks. In the 1920's it became possible to produce both eggs and broilers in confinement when it was discovered that vitamins added to the diet would help to keep the chickens healthy. After World War II vaccines were developed for several poultry diseases and antibiotics were added to the feed. At about the same time automatic devices for delivering food and water to the confined birds were brought to market. Today virtually all eggs and broilers are produced from poultry confined in highly mechanized quarters.

Dairying keeps the farmer at home because cows must be milked twice a day. Milking machines had been developed by World War I, but they were not widely adopted until after World War II. Since then hand milking has come to an end in commercial dairying. Most dairy barns are also equipped with pipeline systems, eliminating the carrying of the milk. In addition a modern dairy barn is equipped with automatic individual drinking cups, power systems for carrying feed to the cows and automatic barn cleaners, which scrape the gutters behind the cows at the push of a button. Electricity provides the power for the automated dairy barn.

Hogs have been taken out of the traditional mud wallow on many farms. They are raised in pens on easily cleaned concrete floors or wood slats. Water and feed are regularly delivered to each pen mechanically.

The mechanization of cattle feedlots has been one of the most spectacular developments in meat production since World War II. Thousands of cattle to be fattened are brought together in a comparatively small space. Carefully formulated feed is mixed mechanically and delivered to them in mechanized carriers and dispensers, and a constant supply of water is available. Studies have shown that this method of fattening livestock is efficient, but it has certain disadvantages. The runoff from rain falling on the densely populated lots pollutes streams, and the large quantities of manure accumulating in the area can present health hazards. Although efforts are being made to solve these problems, their solution is still in the future.

The process of mechanization is unlikely to be reversed once it gets under way. Mechanization demands better farm management for the efficient utilization of capital-intensive equipment. Because some farms will be managed more efficiently than others there will continue to be widening differences among farms in size, production and in-



COTTON HARVESTER represents the latest stage in a long process of mechanization in cotton growing. It is a self-propelled machine that pulls cotton fibers from the bolls by wrapping them around moistened spindles, which are then cleaned off by rotating pads called doffers. The enclosed basket behind the cab holds 636 cubic feet of picked cotton. The detail at the upper right shows the mechanism of the spindles and doffers. The machine shown, made by the International Harvester Co., strips two rows of cotton plants at a time.

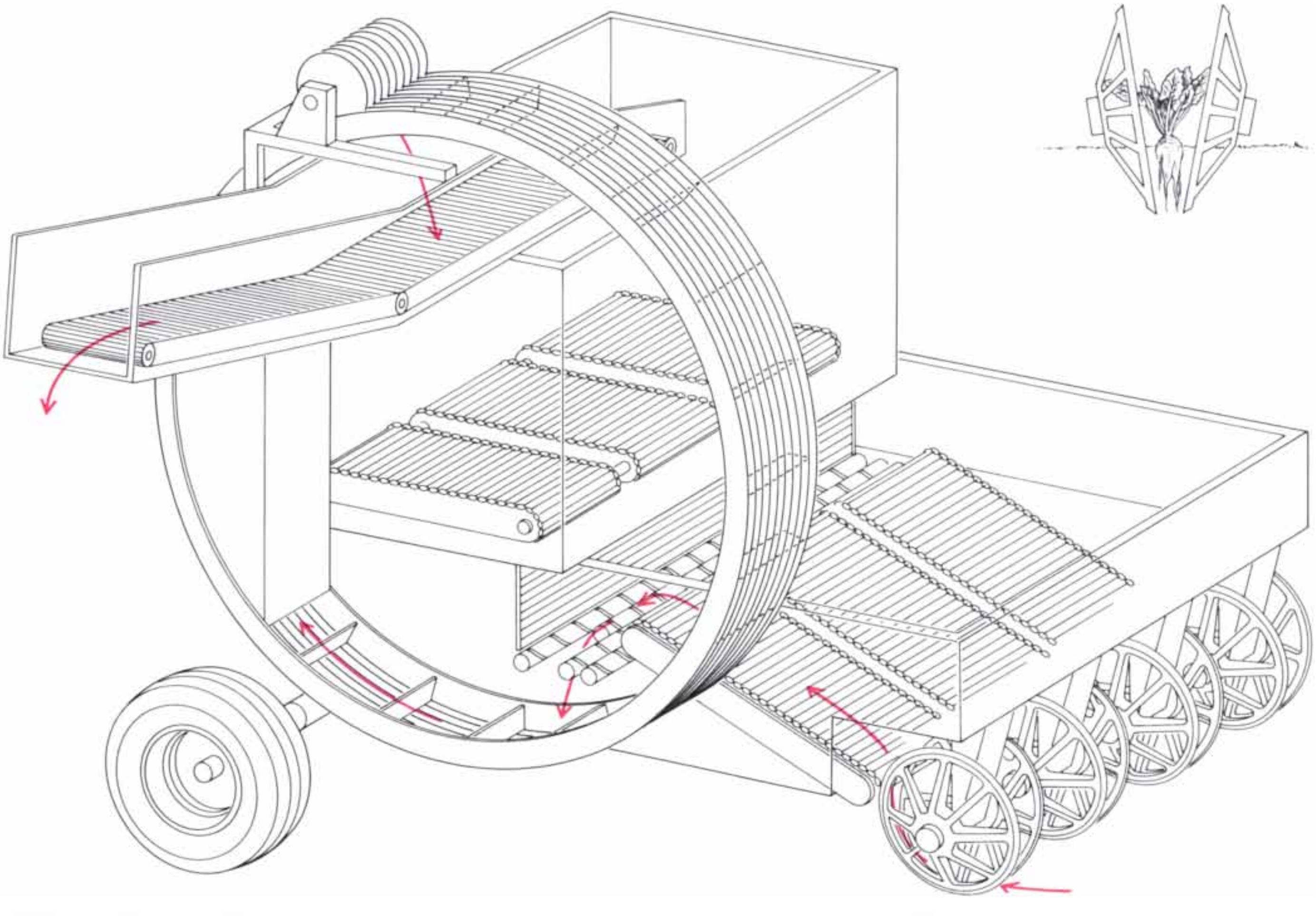
come. Mechanization has reduced opportunities for employment in farming and may continue to do so.

The range of opinion on the economic and social effects of mechanization in agriculture is reflected in the comments of two writers, Theodore C. Byerly of the Department of Agriculture and Jim Hightower, a critic of the established agricultural-research institutions. A few years ago Byerly wrote: "Continuing development and application of technology in production of food, fiber and forest products can supply the next generation abundantly. It can enable them to take the actions necessary to have clean air, sparkling water and a green and pleasant world in which to live." Some two years later Hightower asserted that "in terms of wasted lives, depleted rural areas, choked cities, poisoned land and maybe poisoned people, mechanization research has been a bad investment."

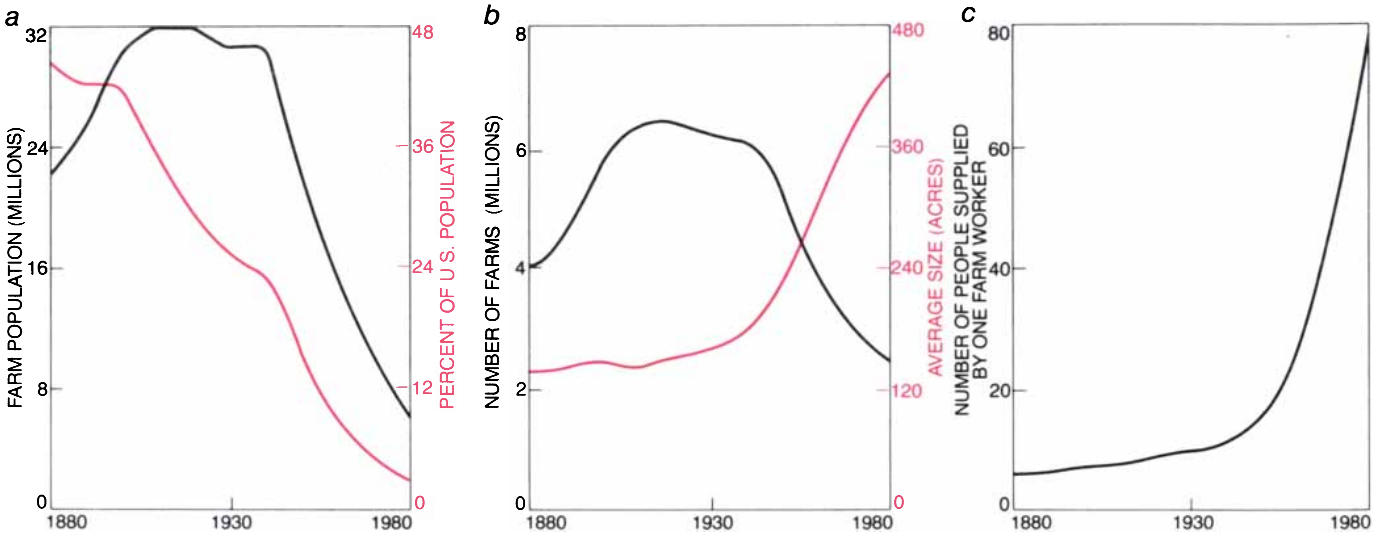
Perhaps some of the contrast lies merely in the emphasis given, because Byerly also stated: "Our newly applied technology has brought indirect and sometimes unforeseen costs. Pesticides have been dispersed throughout our environment. Crop adjustments [government programs under which land was withdrawn from production in an effort to maintain higher prices] have left people without work or means of self-support. Our abundance has cost the taxpayer in funds for supply management and the producer in depressed prices." And Hightower wrote: "This focus on scientific and business efficiency has led to production (and overproduction) of a bounty of food and fiber products."

The hidden costs of farm mechanization and related changes include the decline in the farm population and in the number of farms, the increase in size and capital needed for a farm to survive, the disappearance of many small towns and the loss of rural social institutions. Otha D. Wearin, an agricultural columnist in Iowa, wrote in 1971: "The productive capacity of power machinery has greatly reduced the farm population. Occupied farming units have become fewer and fewer, and farther and farther apart, as producers with power machinery reach out for more and more land to justify their investment. Country churches, country schools, country society and small country towns have suffered. In fact, many of them have completely disappeared." The loss of some rural institutions has been offset in part by improved transportation, but the full significance of these changes has not been assessed.

Golden Valley County in Montana, where I lived on a ranch until my family's business was wiped out by the Depression, illustrates some of these problems. It is still rural, with no industry and with almost no corporation farming (except for family enterprises that are legally classified as corporations). In 1925, the first year for which census data are available, the county had 492 farms with an average size of 637 acres. In 1978 there were 139 farms averaging 4,693 acres. Thus the area under cultivation had doubled, whereas the number of farms had been reduced by two-thirds. The county had 2,126 inhabitants in 1930 and 931 in 1970. The small increase to 1,026 in 1980 was attributable to the founding of a controversial religious colony. In 1925 the county had two banks, two newspapers, two small hospitals, three practicing physicians, a through railroad line and a creamery. By 1980 all these were gone. One of the three high schools had been closed. There is no extension agent from the state agricultural college. The county



SUGAR-BEET HARVESTER digs beets out of six rows with a set of digging wheels, cleans them on the cleaning bed and lifts them on the large wheel into a holding tank. This is a Deere harvester. Until after World War II the sugar-beet industry relied mostly on hand labor, particularly for thinning beets in the spring and harvesting them in the fall. Now, with machines for planting, thinning and harvesting, sugar-beet production in the U.S. is fully mechanized. Monogerm seeds, each of which produces a single plant, helped the process.



GAINS IN PRODUCTIVITY in agriculture and corresponding declines in farm manpower are charted from 1880 for the U.S. farm population (*a*), the number of farms and their size (*b*) and the number of people supplied with food and fiber by each worker on a farm (*c*).

has yet to acquire a radio or television station. On the other hand, the roads have been much improved since 1930.

Perhaps the major economic beneficiary of farm mechanization is the consumer of agricultural products. Expenditures for food as a percentage of consumer income have been declining since World War II and are substantially lower in the U.S. than they are almost anywhere else in the world. Foreign consumers too have come to rely on the American farmer.

Farmers have seen their disposable income increase from $840 per person in 1950 to $6,553 in 1980. For nonfarm people the corresponding amounts are $1,455 and $8,042. In 1950, however, about 31 percent of farm income came from such nonfarm sources as teaching school, driving a bus, selling insurance and working in a store or a factory. By 1980 the share of farm income from nonfarm activities had risen to 63 percent. Farm income from farming has generally not kept pace with increases in productivity.

Mechanization has been the key reason (but not the only one) for the increase in total production and the higher productivity per man-year that have characterized agriculture in the U.S. The output of wheat has risen from 314 million bushels in 1875 to 669 million in 1925 and to 2.4 billion in 1980. Since 1950 the yield of wheat has increased from 16.5 to 33 bushels per acre, of corn from 38 to 91, of soybeans from 22 to 27. The yield of potatoes has risen from 153 hundredweight per acre to 261. The output per man-year in agriculture has improved at a rate of nearly 6 percent per year, compared with 2.5 percent for all other industries.

The number of farms in the U.S. declined from 6.5 million in 1920 to 5.6 million in 1950 and to 2.4 million in 1980. By now the subsistence farmer has almost disappeared from the countryside except for people who have taken up that way of life not out of necessity but by choice. Today's farmer produces for the market rather than for home consumption.

The farm population and the number of farm workers have declined with the decrease in the number of farms. In 1950 there were 23 million people on farms and 9.9 million farm workers; in 1980 the corresponding numbers were six million and 3.7 million. An important question is what has happened to the displaced farm population. In earlier times surplus farm workers supplied much of the manpower needed for the industrialization of the economy. Since the second American agricultural revolution many of the displaced farm people have gone to the cities, often to an impoverished and bleak situation. Others are now among the rural poor.

Another important question is whether or not American society should tolerate or even encourage the persistent erosion of the farm population. Mechanization has helped to keep the family farm viable by enabling the family to work the acreage needed for an economically sound unit. On the other hand, the investment now required to establish a new farm makes it almost impossible for a young family to enter farming unless they can continue on a farm that is already in the family. Even the established farmer finds it difficult to finance the purchase of additional land and new equipment.

Who should be responsible for planning for the workers who might be displaced by new technologies? Certainly not the inventors and technologists. The country cannot continue to maintain agricultural production at a satisfactory level if research is halted. Henry A. Wallace addressed this question in 1940, when he was Secretary of Agriculture and when research was under attack as adding to farm surpluses. "Science, of course, is not like wheat or automobiles," he said. "It cannot be overproduced.... In fact, the latest knowledge is usually the best. Moreover, knowledge grows or dies. It cannot live in cold storage. It is perishable and must be constantly renewed."

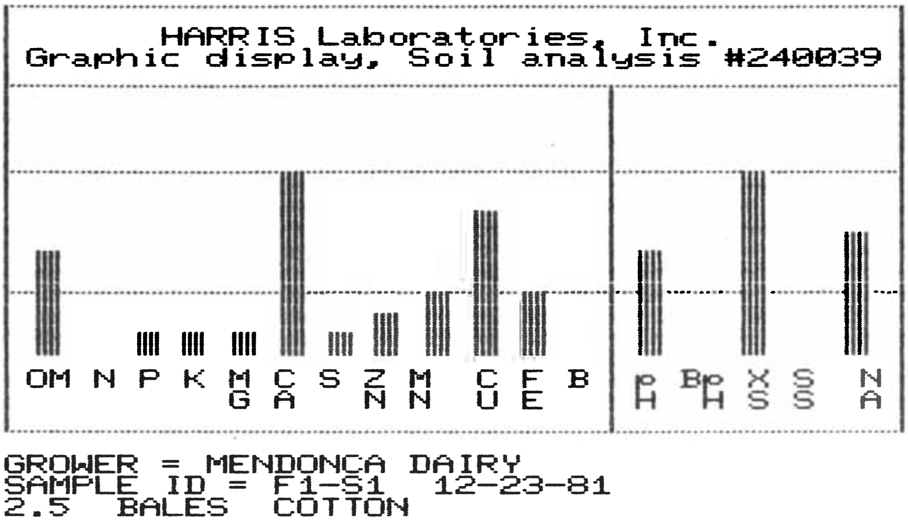
Nor should the manufacturers and suppliers of agricultural equipment be expected to decide whether or not a particular technology should be made available if it might force some people out of work. The Rust brothers found that such restraints did not work with their cotton picker. The answer is not to limit research or stop the production and use of new machines, even though some changes in emphasis may be appropriate for research done with public funds. Farmers and their families today live longer and healthier lives at least in part because of the mechanization of American agriculture. Whatever solution may be found to the problem of disemployed farm workers, it would hardly be humane to return them to dawn-to-dusk labor chopping cotton, thinning beets or flailing grain.

In the early 1980's there are some indications that agricultural productivity may have reached a plateau. At least it is not increasing at the rate that prevailed from 1950 to 1980. The number of commercial farms is still declining, but the rate of decline is lower than it was over the past 30 years. Approximately the same total acreage is being farmed. What is most surprising, the rural population has increased faster than the urban population in the past 10 years. Many of the people who have left the cities are actually living a suburban life in areas formally classified as rural, but there may have been a slight increase in the number of people living on farms.

With one exception, no major further advances in the mechanization of agriculture are now in sight. Indeed, if the future can be judged by the past, no major change will take place until a new source of power comparable to the horse and the internal-combustion engine is adapted to agriculture and adopted by farmers. One can expect workers in agricultural research and manufacturers to continue advancing the technology by improving old machines and designing new ones, particularly machines that reduce the demand for human labor and those that substitute technology for land. These achievements will depend in part on a revival of agricultural research, which for several years has felt the effects of declining expenditures in both the public and the private sectors.

The one exception is the application of computers to farm management, which is already under way and seems likely to have a powerful influence. The computer should lead to more efficient management of machines and energy and should help in other farm operations such as cost accounting, mixing feed and deploying fertilizers and other resources efficiently. Some farmers now have computers of their own, and many others have access to computer systems through their county agricultural agent. Packages of computer programs have been developed to meet the needs of farmers in particular states and communities, and one major computer manufacturer is introducing hardware and software designed to serve small farms.

What might a mechanized American farm be like in, say, 2020? First, it will be a large, commercial enterprise operated by a family. It is becoming increasingly evident that the family farm has several advantages over the corporate farm, particularly because the family provides all or most of the labor, directly supervises the hired workers and has the possibility of deferring profits. Second, the internal-combustion engine will still be the primary source of power unless solar energy has been effectively harnessed. Third, additional mechanization will have further reduced farm drudgery. Machines and automated systems may be available for harvesting fruits and vegetables that in 1982 are still picked by hand, for transplanting plants, for adjusting the flow of irrigation water to individual fields and perhaps even for mending fences. Fourth, the extensive application of computers will have made the farm considerably more efficient. Finally, the farmer and his family will enjoy virtually all the amenities of the city-dweller while still having the feeling of being a group apart that works with soil, water and seed to provide large numbers of other people with a plentiful supply of food.



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HARRIS Laboratories, Inc.
Graphic display, Soil analysis #240039
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SAMPLE ID = F1-S1   12-23-81
2.5   BALES   COTTON
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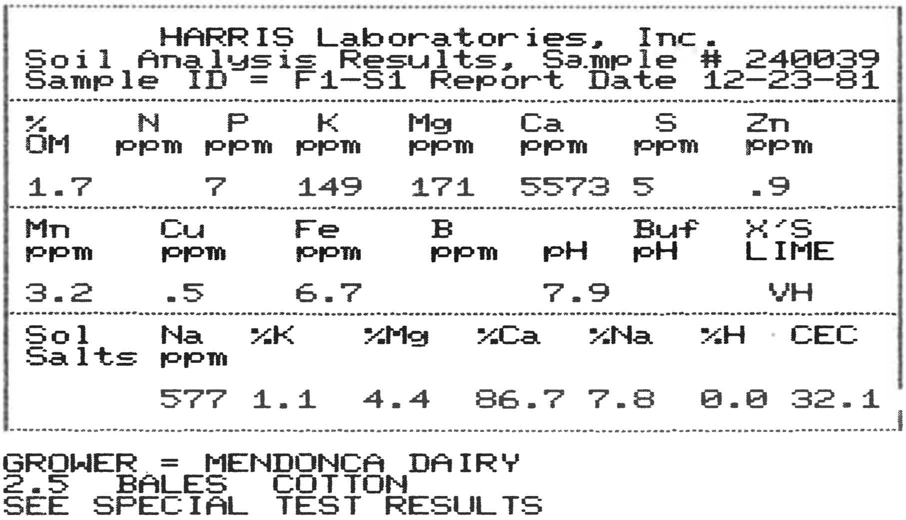

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  Sample ID = F1-S1 Report Date 12-23-81
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 OM    ppm   ppm   ppm   ppm    ppm    ppm   ppm

 1.7      7   149   171   5573   5        .9
 Mn       Cu      Fe      B             Buf    X'S
 ppm      ppm     ppm     ppm      pH   pH     LIME

 3.2      .5      6.7              7.9          VH
 Sol      Na    %K     %Mg    %Ca    %Na    %H    CEC
 Salts    ppm

          577  1.1    4.4    86.7   7.8    0.0   32.1
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GROWER = MENDONCA DAIRY
2.5   BALES   COTTON
SEE SPECIAL TEST RESULTS
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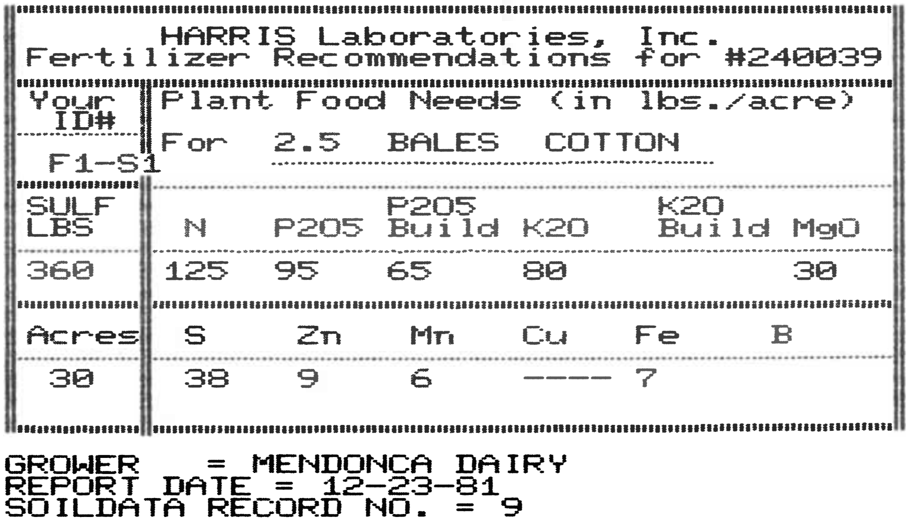

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 Your  | Plant Food Needs (in lbs./acre)
  ID#  |
       | For  2.5   BALES   COTTON
  F1-S1
 SULF  |                  P205          K20
 LBS   |   N     P205   Build   K20    Build   MgO
 360   |  125    95     65      80             30
 Acres |   S     Zn     Mn      Cu      Fe      B
  30   |  38     9      6       ----    7
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GROWER     = MENDONCA DAIRY
REPORT DATE = 12-23-81
SOILDATA RECORD NO. = 9
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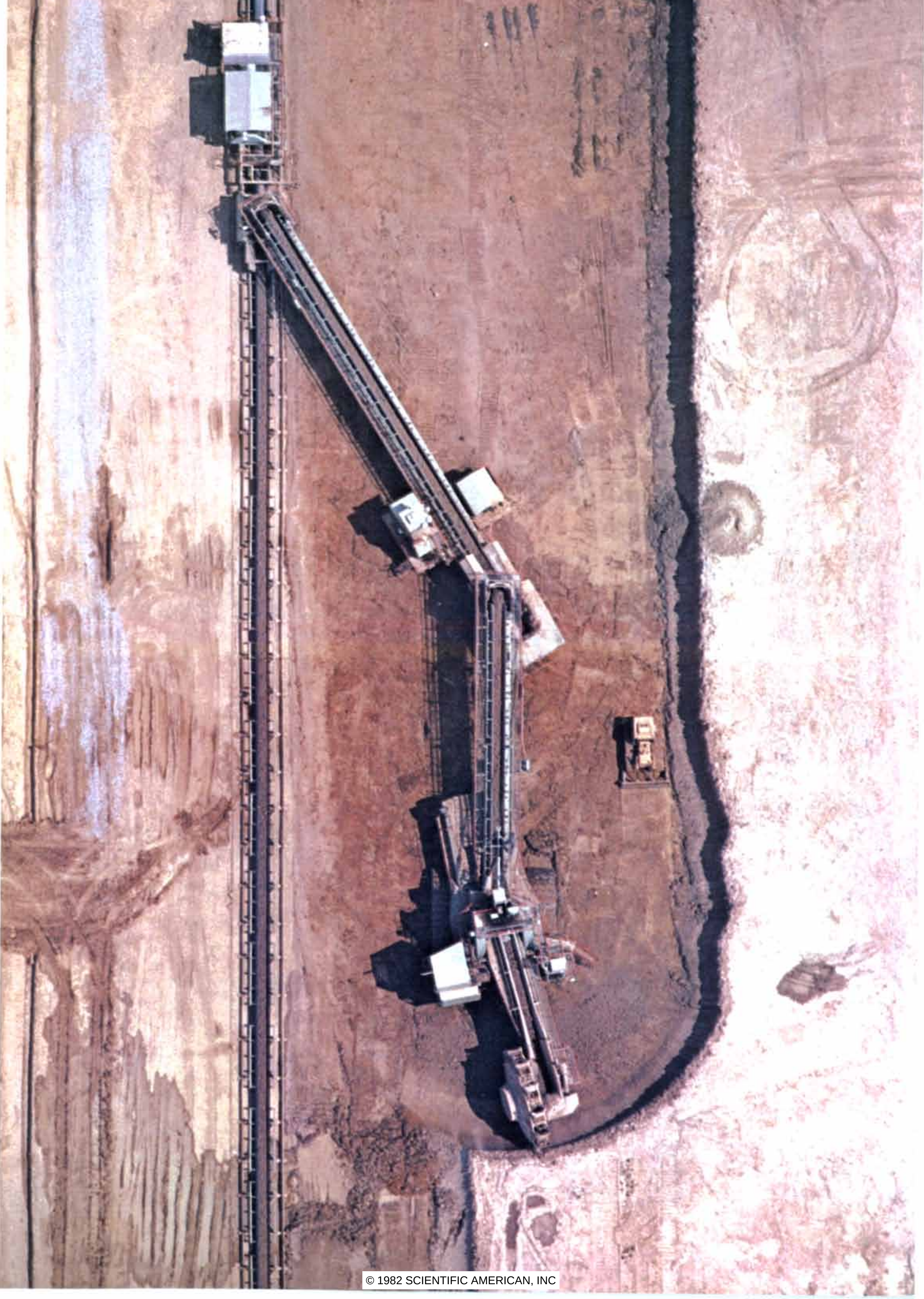
ADVENT OF COMPUTERS in agriculture, which is just beginning, holds the promise of greater efficiency in managing machines and energy and in operations such as cost accounting, deploying fertilizer and mixing feed. A printout like the one shown can be transmitted to a farmer's computer terminal after he has sent a sample of soil to a laboratory to be analyzed. *OM* in the analysis means organic matter; most of the other amounts are in parts per million.



The Mechanization of Mining

Today more than 80 percent of the mineral needs of the U.S. economy are met by only 1 percent of the labor force. Here the mechanization of mining is examined in terms of its effect on the mining of coal

by Robert L. Marovelli and John M. Karhnak

Mining has long been perceived as hard, dirty and dangerous work. It is also the preeminent materials-handling industry, and its products are extracted from the earth in enormous quantities. The work was once done with pick and shovel, and gains in productivity were achieved by increasing the tonnage of material one man could dig in a working day. Now the capabilities of the individual miner are greatly amplified by machines and systems of machines. The changes in technology not only have raised productivity but also have had a pronounced effect on the health and safety of miners.

Various energy sources have long been exploited to augment human labor in mining. Animals provided power to operate pumps for mine drainage and bellows for ventilation. They also transported ore horizontally through the underground workings and hoisted it to the surface. Water power, applied through ingenious systems of gears, spindles and shafts, often took over some of the same tasks. Thermal energy from wood fires was employed to heat rock surfaces, which subsequently shattered when they were chilled with water. This technology was described in detail in 1556 by Georgius Agricola in his treatise *De Re Metallica.*

The development of the steam engine early in the 18th century set the stage for the true mechanization of mining. For the first time the mining of coal and ores could be carried to great depth and horizontal extent with enough power for drilling, cutting, loading, hauling and hoisting as well as for pumping water from the mine and providing adequate ventilation. Mines are not factories, however, and advances in productivity tend to come slowly and at high cost. Many promising machines have proved inadequate and unreliable under actual mining conditions.

The greatest gains in mine mechanization came in a burst of innovation following World War II, when robust new machines were developed, along with new methods for deploying them. It is a tribute to such mechanization that today more than 80 percent of the mineral needs of the U.S. economy can be met from domestic sources with the work of less than 1 percent of the labor force.

A true measurement of productivity calls for a complex analysis of capital and labor costs; in mining geological factors such as mineral quality and accessibility must also be considered. Rapid and often unpredictable changes in these factors further complicate the analysis. Nevertheless, productivity expressed in terms of yield per unit of labor input is an important measure of overall mining efficiency and is the one we shall use in this article.

The effects of mechanization on productivity and on working conditions are deeply intertwined. In coal mining, which is by far the largest segment of the mining industry in the U.S., productivity showed only small improvement until 1950. It then climbed sharply, reaching a peak in 1970 from which it has since fallen back (for reasons we shall describe). Reliance on human muscular exertion has been greatly reduced. Fatalities in mine accidents, which routinely exceeded 2,000 per year until 1930, have been cut by a factor of more than 10. Over this period, however, some hazards to the underground miner's life and health were actually increased by new machinery. A shift to surface mining, or strip mining, since World War II has helped greatly to reduce the number of mine fatalities both because surface mining is inherently safer than underground mining and because the higher productivity of surface mining has lowered the number of workers at risk.

In 1925 some 588,000 men, about 1.3 percent of the nation's labor force, were needed to mine 520 million tons of bituminous coal and lignite, almost all of it from underground. Last year production was up to 774 million tons, but the work force had been reduced to 208,000. Furthermore, only 136,000 of that number were employed in underground mining operations. The highly mechanized and highly productive surface mines, with just 72,000 workers, produced 482 million tons, or 62 percent of the total.

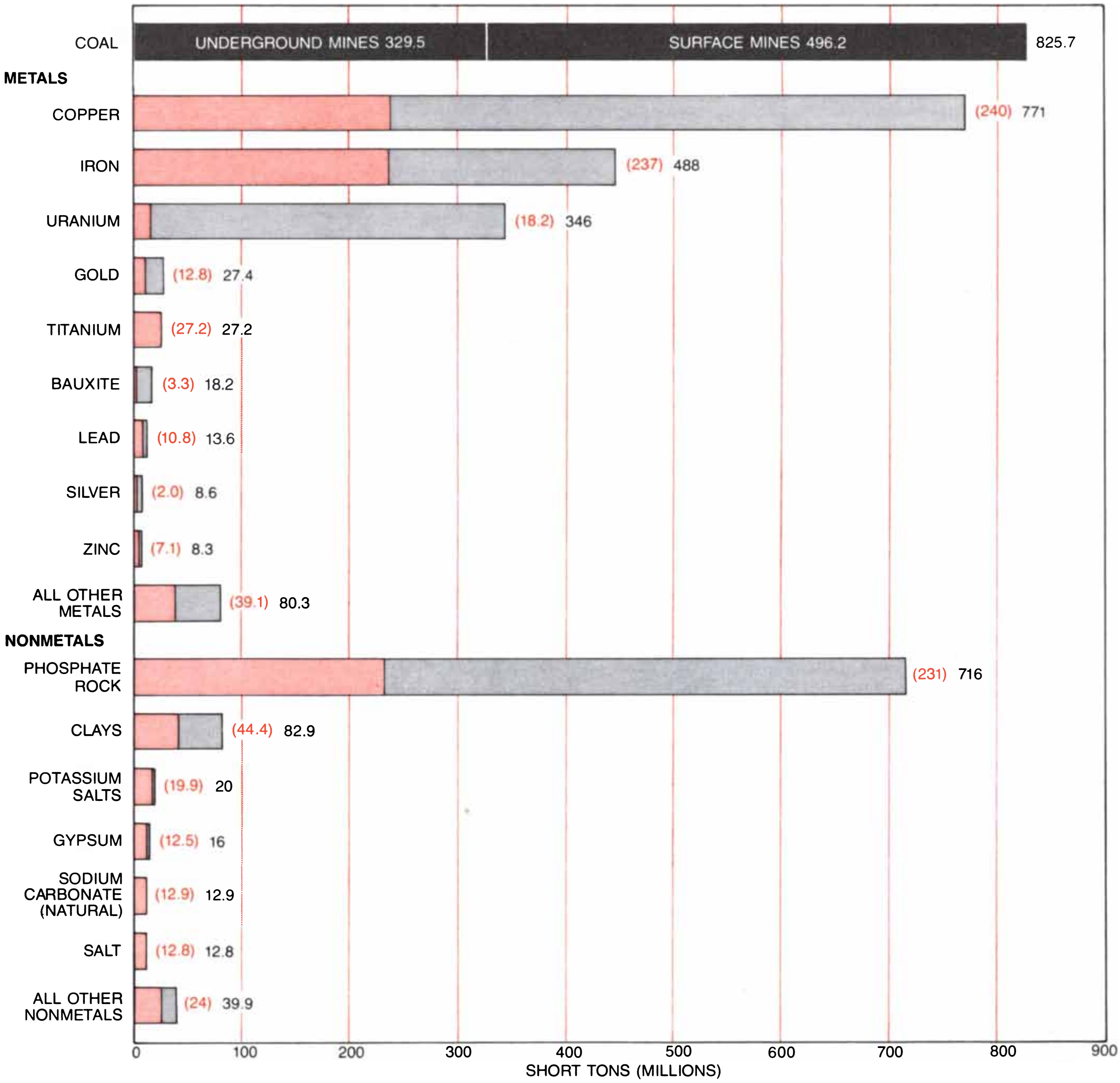
Last year approximately 765,000 men and women were broadly classified as miners, but 300,000 of them, or roughly 40 percent, worked in oil and gas fields and so were miners by definition only. The 208,000 coal miners constituted roughly half of the remainder; another 93,000 were engaged in nonmetal mining and quarrying, and some 57,000 mined a variety of metallic ores (chiefly iron and copper). In addition 107,000 were employed in mills and shops associated with mines; these employees too are classified as miners, although office

BUCKET-WHEEL EXCAVATOR exemplifies the large and costly machines that have been introduced into coal mining in recent decades. The excavator is one of two such machines at the Captain Mine in southwestern Illinois. The mine is owned by the Arch Mineral Corporation and has an annual output of 4.5 million tons of coal. One of the excavators removes the first one or two feet of topsoil; the machine shown strips off the next 15 to 20 feet of earth. The material removed by the two machines is carried more than 8,000 feet by belt conveyors and held in separate piles for eventual restoration of the mined-out land. (State and Federal regulations require that the land be restored to its approximate original contours and, if it was farmland, that there be no loss of agricultural value.) Still more overburden is excavated by shovels and draglines before the first coal seam is reached some 85 feet below the surface. Another 24 feet of earth is then stripped off to gain access to a second seam. The two seams have a total thickness of about 10 feet. Almost 60 percent of the man-hours at the mine are spent in removing the overburden and reclaiming the land and only about 40 percent in mining the coal itself. The excavator is built in West Germany by O & K Orenstein & Koppel Aktiengesellschaft.

workers are not. This work force satisfied 83 percent of the nation's demand for fossil fuels on an energy basis and nearly 90 percent of the demand for all other minerals on a dollar basis, the only common denominator for that diverse category. (Of the 56.4×10^{15} British thermal units of energy derived from domestic fossil fuels in 1981, coal supplied 28.4 percent, petroleum 36.6 percent and natural gas 35.0 percent. The nation's expenditure for all fossil fuels last year was $260 billion, including $77 billion for imported oil; the value of coal at the mine was about $20 billion.)

Last year's production of 774 million tons of bituminous coal and lignite exceeded preliminary estimates of the combined tonnages of the next three minerals in greatest demand: iron ore (246 million tons), copper ore (306 million tons) and phosphate rock (203 million tons). Of materials removed from the earth coal was exceeded in tonnage only by crushed and broken stone (873 million tons). If account were taken of the huge mass of earth and rock that had to be removed to gain access to the 482 million tons of coal produced by surface mines last year (estimated at 10 tons of overburden for each ton of coal), the coal industry would far surpass all other industries in mass of material handled.

Today few minerals are mined primarily underground and most of those are of low tonnage. The principal metal-



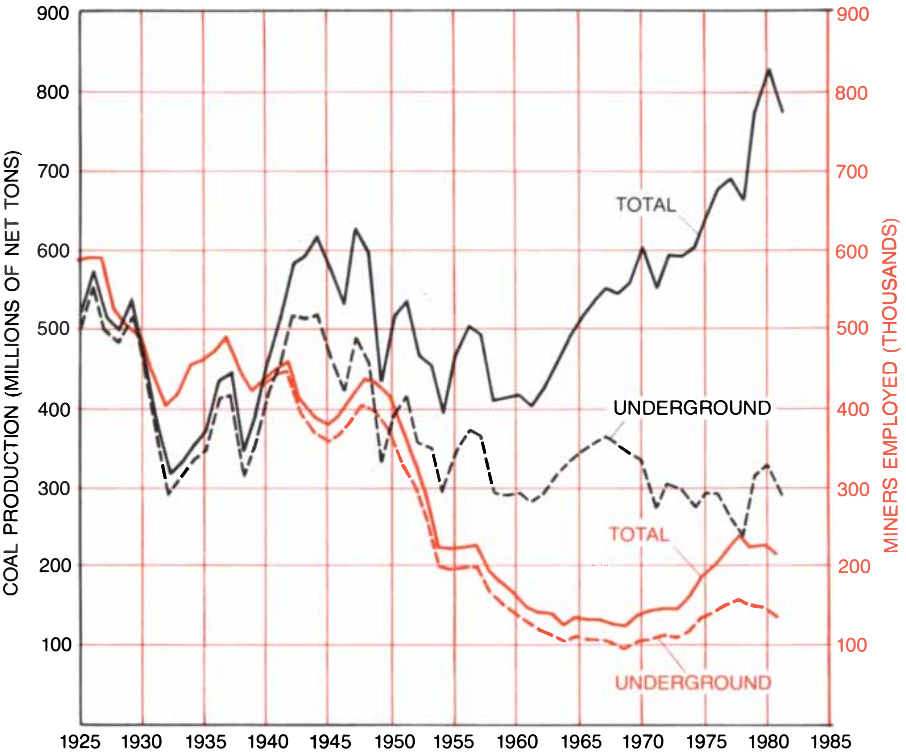
OUTPUT OF U.S. MINING INDUSTRY is dominated by coal: 825,700,000 tons of bituminous coal and lignite in 1980, the most recent year for which a comparison with other mineral products can be made. The bars for the other minerals show the total tonnage of material handled, including waste (*gray*), and the net amount of usable crude ore recovered (*color*). Although comparable data are not collected for coal, the tonnage of waste material handled in surface mining, which accounted for 60.1 percent of the total production, probably exceeded 4,000 million tons. This unrecorded tonnage represents the great overburden of earth and rock that had to be removed to get at coal seams lying as much as 200 feet below the surface. Not shown are two high-volume but low-value products of the mining industry: sand and gravel (794 million tons) and crushed and broken stone (1,060 million tons). Compared with coal, the 1980 domestic production of petroleum was about 570 million tons (3.7 billion barrels) and of natural gas 450 million tons (20.1 trillion cubic feet).

lic ores obtained entirely or in large part from underground sources are antimony, lead and tungsten (from 98 to 100 percent underground), molybdenum (62 percent) and silver (60 percent). Among nonmetals only three major substances are extracted primarily by underground mining: potassium salts, sodium chloride and natural sodium carbonate. The number of American miners who spend their working days belowground does not exceed 160,000, and about three-fourths of these are coal miners. The variety and the quantity of materials obtained by surface mining are much greater. About 95 percent of all metallic ores and 75 percent of all crude nonmetallic ores come from surface mines.

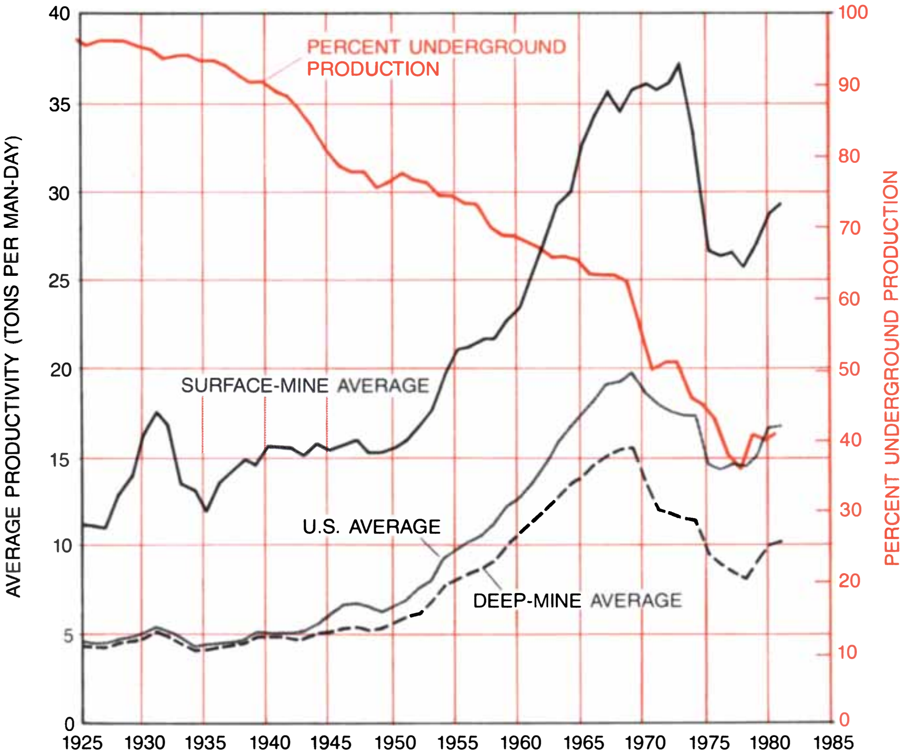
In the surface mining of iron and copper ore improvements can be attributed chiefly to economies of scale: larger earth-moving machines, larger drill holes for blasting and larger shovels for loading larger trucks. In describing productivity in the mining of iron ore, however, one must distinguish between the output of crude ore and the output of usable ore. In copper mining the distinction is made between tons of crude ore and tons of recoverable metal. In both cases greater productivity in the mining of crude ore has been partially offset by a decline in the metal content of the crude material. Since 1952 the output of crude iron ore in long tons per man-year (the traditional measure in that industry) nearly quadrupled from about 3,600 to 12,700. Over the same period the output of usable ore increased about 50 percent, from 2,750 to 4,200 long tons per man-year. The peak of 5,200 long tons came in 1972.

Productivity gains in copper mining over the same period were substantially lower. Between 1950 and 1981 the output of crude ore per man-year increased from about 3,700 short tons to a little more than 9,000, but the output of recoverable metal rose at a much lower rate, from 35 tons to 50 tons per man-year. In 1950 each ton of copper ore mined yielded an average of 19 pounds of copper; by 1981 the average yield had dropped to about 11 pounds per ton.

In open-pit copper mining there are three basic operations: drilling blast holes, loading trucks and hauling the ore. An industry analysis has shown that the smallest productivity increase has been achieved in hauling, even though trucks of much greater capacity are now in operation. The reason is that as the pit is made larger and deeper the ore must be hauled and lifted farther. It appears that economies of scale have reached a temporary plateau in open-pit copper mining. The industry expects that future gains can be made with the aid of computers to improve the coordination of the mining system, by the use of self-propelled scrapers and crushers and by



HISTORY OF COAL MINING in the U.S. since 1925 is marked by sharp swings in demand and in the size of the work force (*color*). The biggest change, however, has been the shift away from underground mining since World War II. As late as 1945 some 94 percent of the nation's 383,000 miners worked in underground mines. Today there are only about 208,000 miners, and fewer than two-thirds of them labor underground. In the late 1920's the average miner produced about 950 tons of coal per year. The present output is about 3,700 tons per man-year.



PRODUCTIVITY PER MAN-DAY in coal mines crept upward at a rate of only 1.6 percent per year between 1925 and 1950. In the next 20 years, however, with the introduction of continuous mining machines belowground and of larger earth-moving machinery in surface mines, output per man-day climbed at an annual rate of 5.3 percent. Some of the productivity gains have since been lost, partly because of Federal legislation designed to improve miners' health and safety. After 1974 surface-mine productivity fell sharply for a number of reasons, including land-reclamation laws. In the past three years productivity has begun to rise again.

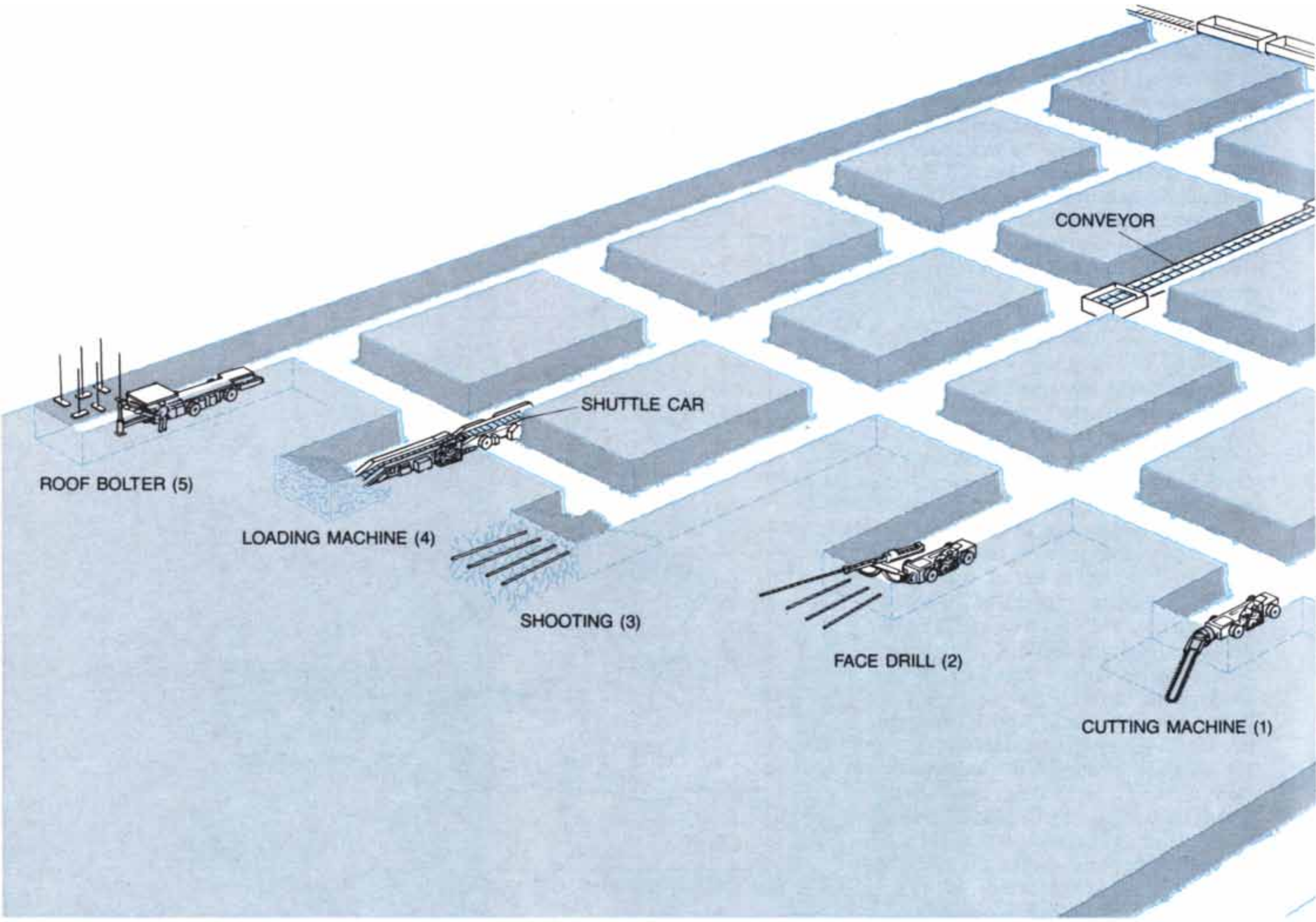
adopting belt conveyors for difficult long hauls.

Mechanization in coal mining can be traced almost to the beginning of the industry. Some of the first steam engines were put to work pumping water from mines, and they were later applied to mine ventilation and the transport of men and materials from the surface to the mine-working level. A few steam-powered drills and haulage locomotives were used underground, but they were soon replaced by devices driven by compressed air. Beginning in 1888 electricity became available in the mines, supplying light and power for machinery. By the early 1900's power equipment was commonplace in American coal mines for a number of operations, including the drilling of blast holes and the undercutting of the coal face in preparation for blasting. By the end of World War II 90 percent of the coal mined in the U.S. was undercut by machine.

In spite of early progress in the mechanization of underground coal mining, the improvement in productivity in the first half of the 20th century was far from dramatic. In 1897 a man with a pick and shovel could mine three tons of coal per day. In 1925 the average miner's output in a somewhat shorter working day was 4.5 tons. By 1945 productivity had increased by only a little more than 10 percent, to five tons per man-day. In comparison the gains since then have been remarkable. In 1969 productivity briefly reached 15.6 tons of coal per man-day, and the work force required by underground mining operations had shrunk to 99,000.

The decline in productivity in the 1970's can be attributed to several factors. The low point of 8.4 tons per man-day came in 1978, and employment in underground mining rose in proportion (to 160,000). One important cause was unquestionably the institution of more stringent safety regulations; another was labor strife. The diminishing quality of the accessible resources also contributed: in all forms of mining the most accessible deposits are worked first, and so mining tends inevitably to become more expensive as it is extended deeper into the earth or to more distant sites. Some mine operators contend that mechanization itself is a third cause of lowered efficiency; reliance on larger but fewer machines, they point out, makes the mining operation more susceptible to interruption as a result of breakdowns. Whatever caused the loss of coal productivity, the recent recovery has brought it up to about 10 tons per man-day.

Strip mining, with its potential for mechanization on a vast scale, grew little until World War II. Between 1925 and 1941 the output of surface mines increased only slowly, from 3.2 percent



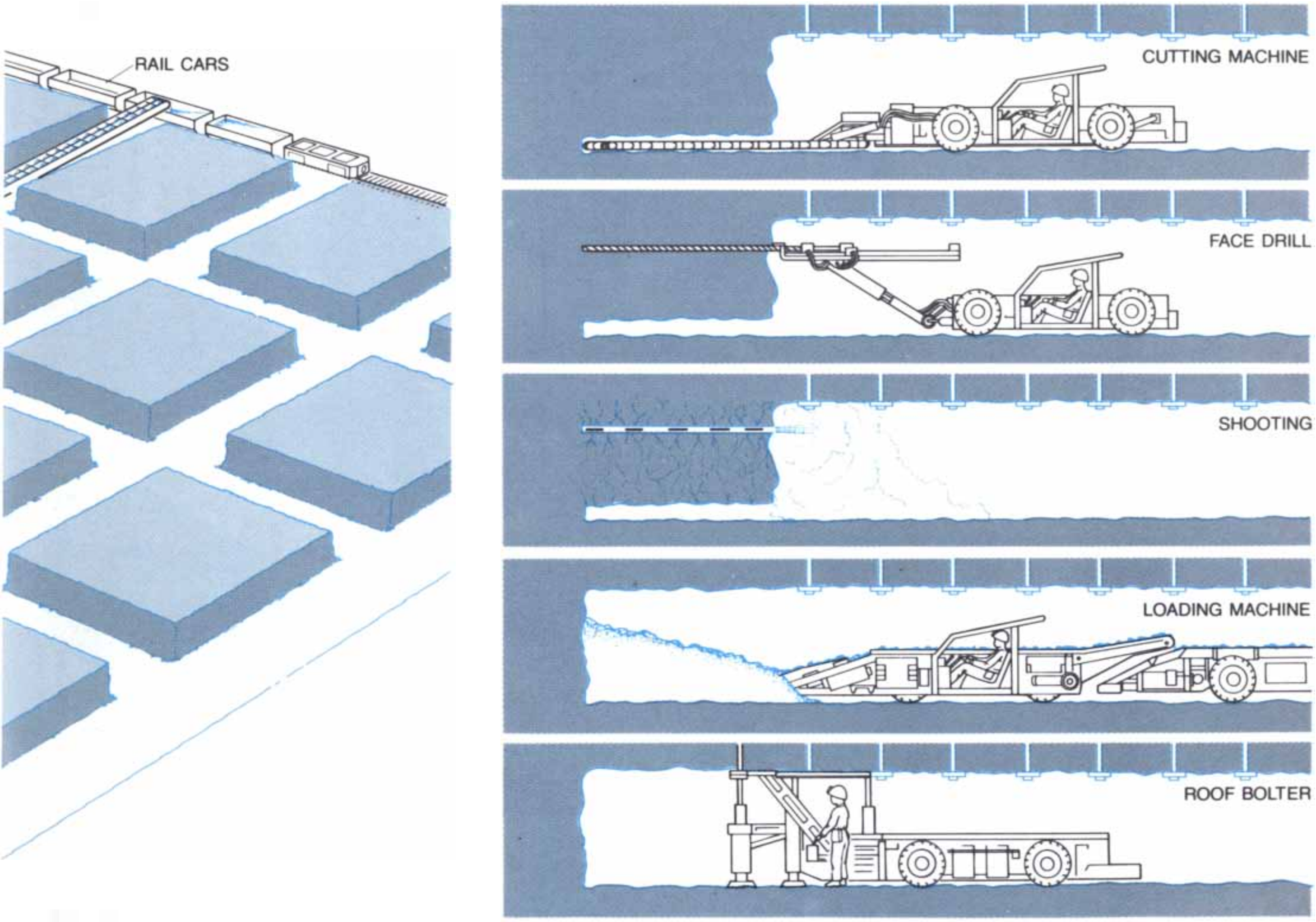
ROOM-AND-PILLAR MINING has been the standard method of underground coal mining in the U.S. since the 19th century. The rooms are empty areas from which coal has been removed; the pillars are blocks of coal from 40 to 80 feet on a side, left standing to support the roof of the mine. In the final stage of the mining of a seam the coal in the pillars can be extracted, allowing the roof to fall. In conventional mining, diagrammed at the left, five operations are carried out in sequence. Typical machines for the operations are shown at the right. In the first step a slot roughly six inches high and 10 feet deep is cut across the base of the seam by a machine with a long cutter of total coal production to 9.2 percent. By 1945, however, the share of coal coming from surface mines had more than doubled to 19 percent. As noted above, strip mines now account for 62 percent of American coal.

The productivity of surface mining has consistently been higher than that of underground mining. The productivity was about 11 tons per man-day in 1925 and 15.5 tons in 1945. A peak of 36.7 tons per man-day was reached in 1973. As in underground mining, a substantial decline followed. New requirements imposed on mine operators were among the reasons for the decline, although in surface mining the requirements had to do not so much with safety as with the restoration of the mined lands to their approximate original contours and agricultural quality. Productivity fell to less than 26 tons per man-day in 1978, but it has since recovered and is now approaching 30 tons.

Whereas the productivity of surface mining has been paced in large part by increases in the size and efficiency of earth-moving and ore-moving equipment, productivity gains in underground mining have required the introduction of new technology. This has been particularly true of coal mining. One of the principal deterrents to technological innovation has been the geological diversity of coal seams. In West Virginia coal is mined from seams as thin as two feet and as thick as 18 feet. Most of the seams are quite flat and many can be entered directly from the side of a hill. Few West Virginia mines are more than a few hundred feet below the level of surface transportation. In Colorado, in contrast, some mines are 3,000 feet deep and have seams dipping 30 degrees from the horizontal. There is also diversity in the size of mines, with output ranging from a few thousand tons per year to more than 15 million.

Because coal deposits are widespread in the U.S. coal mining has attracted thousands of small operators. Between World War I and World War II the number of bituminous mines ranged from about 5,400 to more than 9,300, with virtually as many mining companies. Today some 3,500 companies operate about 6,000 mines. The largest company, the Peabody Coal Company, mines no more than about 8 percent of the total; it takes 50 of the largest companies to mine 65 percent.

The typical underground coal mine in the U.S. is laid out in a checkerboard of rooms and pillars, a mining method dating back to the 19th century. The rooms are empty spaces from which coal has been removed. The pillars are blocks of coal from 40 to 80 feet on a side left standing to support the roof of the mine. The deeper the mine is, the larger the pillars must be. Eventually



bar. A series of holes, also about 10 feet deep, are then drilled in the face of the coal above the slot and are loaded with explosives. The detonation of from 10 to 15 pounds of explosives fractures up to 50 tons of coal, which spills out onto the floor of the mine. A loading machine conveys the shattered coal into a waiting shuttle car, which hauls the coal to a belt conveyor. The belt in turn carries the coal to the main haulage line (which can be another belt or a rail line) for transport from the mine. The final step is to insert a series of long steel bolts into the roof in order to bind the overlying layers of shale into a strong laminate. The sequence of operations is then repeated.

the coal in the pillars can be recovered by mining the pillars at the farthest point of advance and retreating to the mine entrance, letting the roof collapse in a controlled way as pillar after pillar is salvaged.

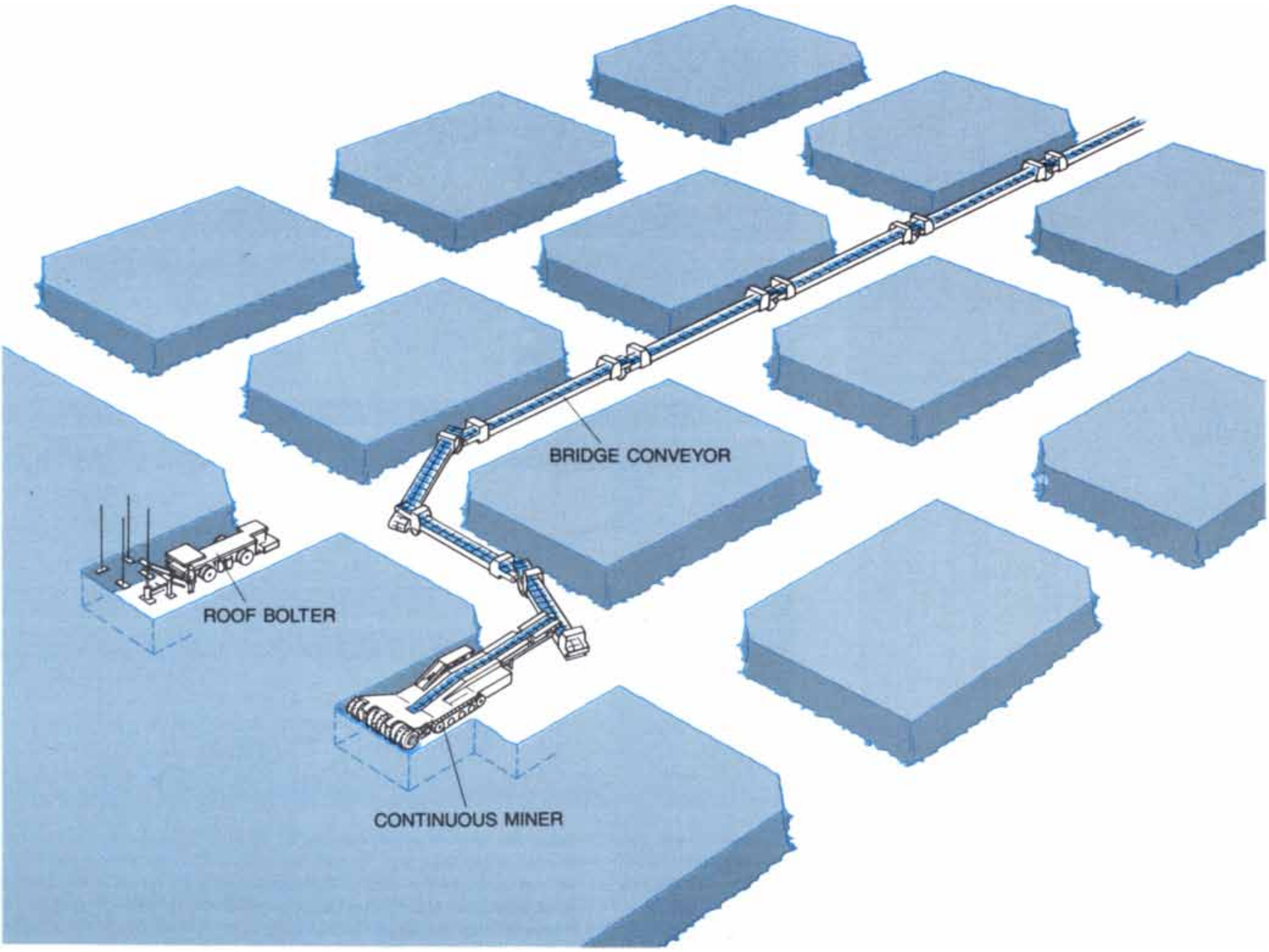
A room-and-pillar mine is opened by excavating entry and exit tunnels in the virgin coal. Miners and machines are transported to the working faces of the mine by an underground railroad, which may also haul away the coal. The mining proceeds from multiple "entries" cut parallel to the main haulage lane and reached by cross tunnels. The sequence of mining operations at the coal face in 1947 would have been familiar to a miner of 1897, except for the replacement of muscle power by machines.

In conventional mining the energy needed to dislodge coal from the seam is supplied by chemical explosives. In the 1940's American coal mines annually consumed almost 500 million pounds of explosives, about half of the amount used in all mining and quarrying and some 40 percent of all explosives sold for industrial purposes. (Last year the coal industry used an estimated 2.25 billion pounds of explosives, which was half of the industrial total; 98 percent of this amount, however, was consumed in surface mines.) To make the blast effective a slot six to eight inches high and about 10 feet deep is first cut in the base of the seam. The undercutting is now done by a machine equipped with a movable cutter bar that resembles a chain saw; in 1897 a miner used a pick to hack out a smaller slot. The slot provides an additional free face into which the coal can expand when it is blasted.

The next step is to drill a series of holes into the face of the coal parallel to and above the slot. The holes are two inches in diameter and 10 feet deep, and they are spaced about two feet apart. Each hole is loaded with between seven and nine sticks of explosive. Ten to 15 pounds of explosive will shatter up to 50 tons of coal. The explosive charge is wired with electric blasting caps and detonated from a safe distance. The resulting pile of shattered coal is scooped up from the mine floor by a loading machine with two crablike arms and conveyed to a waiting shuttle car or other haulage device. By 1947 some 60 percent of underground coal was mechanically loaded. More than 10,000 animals, however, most of them mules, were still employed for haulage.

The final step in room-and-pillar mining is to support the newly exposed roof. In 1947 the standard roof support was a framework of heavy timbers. A year earlier, however, a few coal mines had begun experimenting with roof bolts, which had been introduced as early as 1927 in the mining of minerals other than coal. The steel bolts are commonly four to six feet long, and they are generally inserted at intervals of every four feet in a gridlike pattern. The bolts are held in place either by a mechanical expansion shell or, more recently, by polyester resin. The bolts bond the various rock strata overlying the coal seam to support the mine roof. It was by these methods that the average underground mine of 1947 achieved an output of five tons of coal per man-day. The most fully mechanized mines, with seams up to 11 feet thick, attained a productivity twice as great.

By late 1948 the first models of a continuous mining machine were being secretly tested in several mines. The machine, which was built by the Joy Manufacturing Company of Pittsburgh, removed and loaded coal from the solid face in one step. The original machine

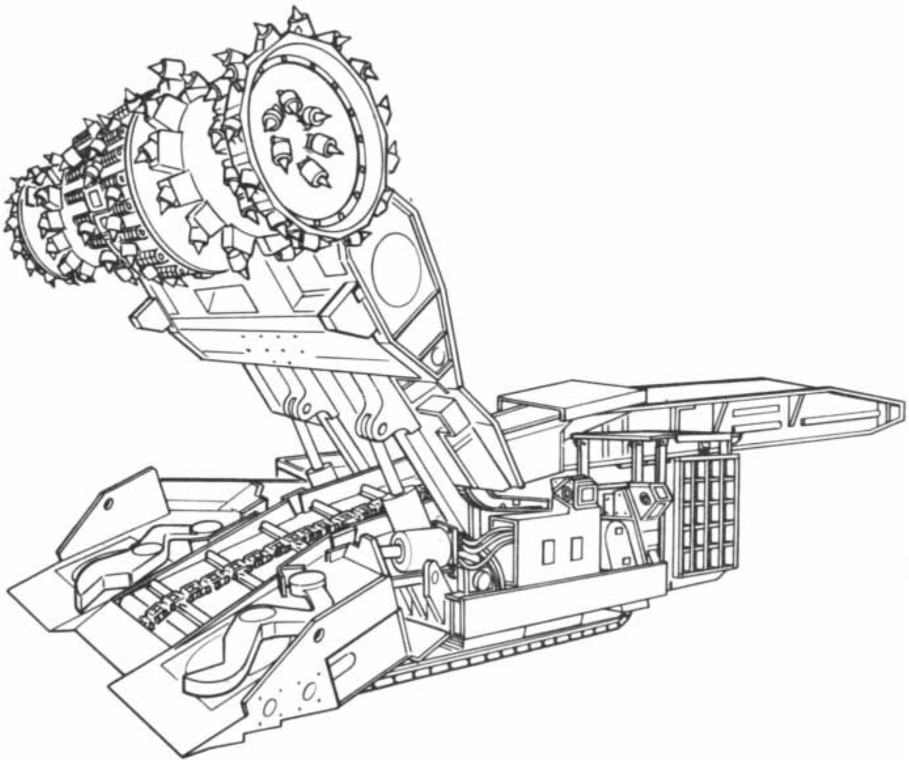


had a gang of cutter chains mounted vertically on a swiveling head; the chains were driven into the base of the coal face and then ripped the seam upward from the floor to the roof. The coal was carried to the rear of the machine by a conveyor and dropped into a waiting shuttle car. The Joy company stated that its machine could raise productivity in a typical mine to 15 tons per man-day.

The industry was skeptical. Many of its customers paid a premium of several dollars per ton for coal delivered in sizable chunks. If the new mining machine increased the fraction of small cuttings and "slack" (pieces less than three-eighths of an inch in diameter), most of the incentive for higher productivity would be wiped out. Some mining engineers also questioned the economics of fracturing coal by electrically driven machinery when that step could be done cheaply with explosives. At the time the question seemed so important that a continuous miner expressly designed to minimize the cost of fracturing coal was financed by an industry-supported organization, Bituminous Coal Research, Inc. The machine was unsuccessful. As improved models of the Joy miner and competitive machines were developed, the industry's skepticism slowly abated.

Continuous mining machines being made now are larger and more powerful than the original Joy machine but work on the same principle. The main difference is that the cutter chains have been replaced by a rotating drum about two feet in diameter and from eight to 16 feet wide; it is fitted with steel bits tipped with silicon carbide cutting edges. The drum turns at about 60 revolutions per minute. It is driven into the top of the coal seam a distance nearly equal to its diameter and is then moved downward, shattering the coal. The fractured coal is pulled to the center of the face by gathering arms, then transferred by a conveyor to a waiting shuttle car or to another conveyor. When the machine has advanced 20 feet or so, it is moved to another place and the exposed roof is bolted. Continuous mining machines were widely adopted in the late 1950's and the 1960's, and now almost two-thirds of all underground tonnage is extracted in this way.

As coal mining is extended to greater depths, larger pillars must be left to support the overlying strata. Although overall coal extraction can be raised from about 50 percent to 70 percent by removing the pillars in reverse sequence and allowing the roof to collapse, such retreat mining requires a great deal of skill and experience, and it can be more dangerous than other forms of mining. As a result an alternative to room-and-pillar mining has received increasing attention. It is known as longwall mining, and it has been practiced for many years in deep European mines.



CONTINUOUS MINING MACHINES, which first appeared in 1948, also operate in a room-and-pillar mine layout. The machines fracture coal from the face of the seam and load it in a single step. Modern continuous miners are built in several sizes to operate in seams that range from two to 10 feet in thickness. The most widely adopted machines have a rotating drum studded with cutting bits that dig into the coal face. The drum is driven into the top of the seam and travels downward. Gathering arms push the fallen coal onto a central conveyor that discharges the coal onto a haulage system, such as a shuttle car or an extensible conveyor belt coupled to the rear of the continuous miner. After the mining machine has advanced about 20 feet it is withdrawn and moved to another face so that the freshly exposed roof can be bolted. Continuous mining machines now account for about 65 percent of all coal mined underground.

Longwall mining is a technology for extracting a continuous block of coal. The block is usually from 400 to 600 feet across the face, and it can be as much as a mile long. A specialized machine, either a plow or a shearer, travels along the face on a guide or track, cutting the coal and depositing it on a conveyor that carries it out to a main haulage junction at the end of the face. An essential element of the longwall method is a system of movable roof supports that hold up the roof over the immediate work area along the entire length of the face. As the mining machine is advanced into the face the supports are advanced with it, allowing the roof behind the supports to cave in.

Until the mid-1970's longwall mining found little favor in the U.S. It had been tried in the Illinois coal fields as early as 1962, but a series of failures discouraged others from adopting it. In 1975 fewer than 60 faces were in operation. In that year, however, a few mines in Illinois, the site of earlier failures, installed a new system of hydraulically operated shield-type roof supports that had been developed in Europe. By 1979, 91 longwall faces were in operation. At last count there were 105 active longwall faces, with equipment for 21 more on order. In 1981 longwall mines accounted for 18 million tons of coal, or 6.2 percent of underground production. According to some estimates, about 200 longwall faces will be operating in the U.S. in 1985, yielding as much as 12 percent of all underground tonnage.

High productivity is possible in longwall mining. The Sunnyside Mine of the Kaiser Steel Corporation at Sunnyside, Utah, regularly extracts 2,900 tons of coal per day with an 11-man crew from a face 550 feet long, well above the average U.S. productivity. The coal seam, which is nine feet thick, lies 1,500 feet below the surface. In one 24-hour period earlier this year a series of crews working one face produced 20,384 tons of coal, a world record.

The question arises of why the apparently more productive longwall technology has not spread faster in the U.S. One reason is that American mines are generally shallower than those in Britain, West Germany and other countries that are fully committed to the longwall method. Room-and-pillar mining is therefore still economical in most U.S.

coal seams. Moreover, American mining engineers and workers have had only limited experience with the longwall system. As in other fields, management has learned that pioneering can be costly. The capital investment needed to open a new longwall face is high: from $10,000 to $14,000 per foot of face length, so that a 500-foot face would cost from $5 million to $7 million. In addition continuous mining machines are still needed for development of the mine. Customary marketing arrangements for coal also have an influence on the choice of methods. In the U.S. the output of a mine is usually sold by contract with the assurance of regular shipments to customers. A mine with a single longwall face runs the risk of defaulting on contracts if a mechanical breakdown interrupts operations. To ensure continuity of production the operator must open multiple faces, which raises the capital cost still further.

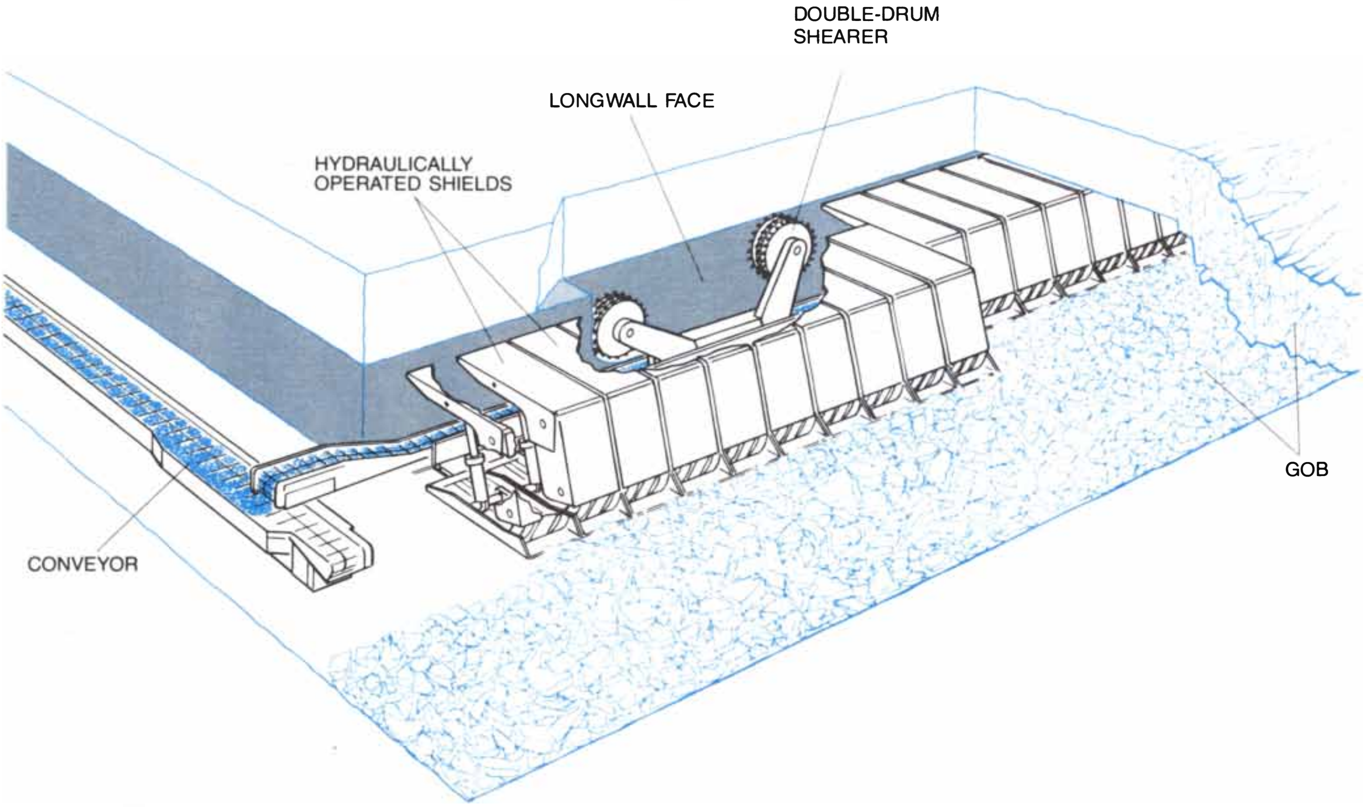
Because longwall mining is likely to assume increasing importance in the U.S., the experience in the U.K. with longwall mining is pertinent and somewhat sobering. It suggests that the gains from mechanization can be canceled by geological conditions and other factors that are difficult to control. Between 1971 and 1980 the number of operating longwall faces in the U.K. was reduced more than 20 percent, from 840 to 649, reflecting the closure of marginally productive mines. A recent analysis by Brian Lord, chairman of Lord International Mining Associates, shows that in spite of the concentration of output in the better mines, there was no overall improvement in the productivity of longwall mines between 1971 and 1979. It turns out there was a productivity gain of 16 percent at the coal face itself, but it was offset by a decrease in productivity "elsewhere underground." Overall productivity remained constant at 2.24 tons per man-shift.

When Lord classified the longwall mines according to their degree of mechanization, he found that the most mechanized mines were slightly less efficient than the least mechanized ones over the most recent five-year period, 1975 through 1979. The measure of performance was the distance the coal face was advanced in centimeters per man-shift. The least mechanized mines nosed out the most mechanized ones 87 centimeters to 86 centimeters. The best performance was that of mines with intermediate levels of mechanization: 91 centimeters per man-shift.

These surprising results prompted Lord to question whether the British coal industry should pursue the goal of a fully mechanized coal face. He speculates that the industry is already overmechanized and that a simplification might prove beneficial. Between 1946 and 1980 the nationalized British coal industry made a massive effort to modernize its mines. The technological achievement was impressive: the number of miners was reduced by two-thirds, from 711,000 in 1947 to 237,000 in 1980, while output declined only 30 percent, from 187 million long tons in 1947 to 130 million in 1980. Thus production per man-year slightly more than doubled. The economic benefits, however, are questionable: in 1980 the return on average capital invested was exactly zero.

With respect to the mechanization of mines in West Germany similar conclusions have been reached by Gunter B. Fettweis, director of the Institute for Mining Technology of the University of Mining and Metallurgy in Leoben, Austria. He has found that mechanization brings substantial savings initially, when the geological conditions are favorable. As the coal becomes harder to extract, however, the costs in a mechanized mine rise sharply and soon exceed the costs in less mechanized mines where the geological difficulty is comparable. The explanation, Fettweis writes, "is that machines up to now have almost always proved less able to adapt to difficult or changing conditions than people working manually. Under very unfavorable conditions [men and machines] fail together."

American coal operators are beginning to have similar reservations about the benefits of extreme mechanization, according to Paul C. Merritt and David



Brezovec of *Coal Age*. Some operators contend that mining is becoming too sophisticated and that the functions given over to machines increase the probability of shutdowns. Individual machines, in many cases those meant to make the job easier, often prove unreliable under actual mining conditions.

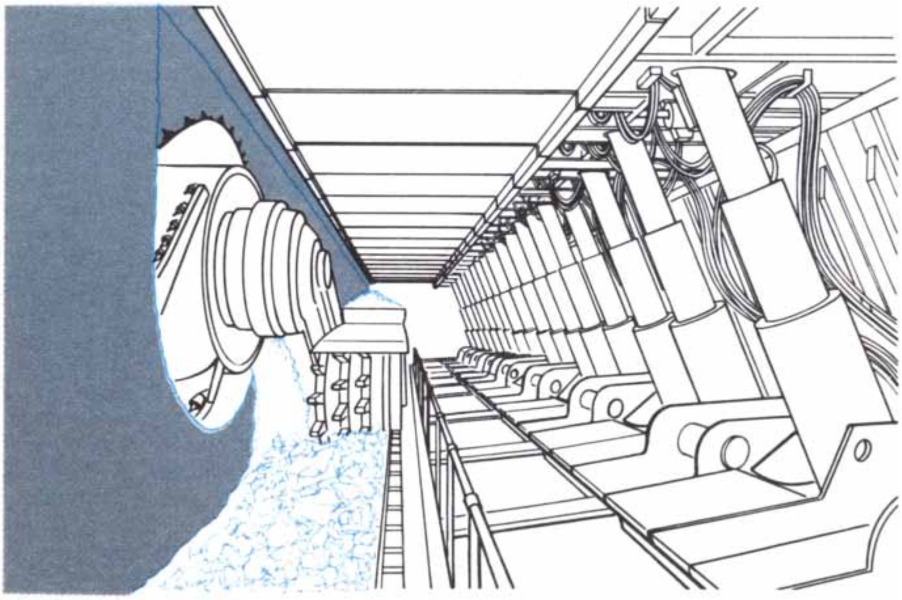
The difficult problem of trying to raise mining productivity above levels that are already high suggests to some observers that the roles of private industry and government should be redefined. In some American industries the Federal Government takes a direct hand in research and development; for example, the National Aeronautics and Space Administration contributes to the design of aircraft and the Department of Agriculture contributes to the improvement of crops and animal husbandry. In mining, however, the Government (through the Bureau of Mines) has concentrated more on efforts to improve the health and safety of miners than on efforts to increase productivity. Research on productivity (assumed by the Department of Energy in 1977) has been hampered somewhat by the diversity of conditions encountered in mining. One suggestion is that private industry should concentrate on simplifying and increasing the reliability of existing equipment, whereas government should attend to more speculative areas of technology, including efforts to ensure that greater mechanization will pay off in improved productivity and safety.

One example of a promising idea that proved to be ahead of its time was the "push-button miner." In many areas, and particularly in Appalachia, strip mining can reach only part of a coal seam; operations must be suspended where the ratio of overburden to coal mined exceeds an acceptable value. Additional coal can be recovered by driving large augers into the hillside. In the 1950's and 1960's auger mines accounted for some 10 to 20 million tons of coal per year, or from 2 to 3 percent of total production. The productivity of auger mines was as high as 45 tons per man-day, about 10 tons higher than the peak productivity of strip mining.

In the early 1960's one company tried to develop an automatically controlled coal auger: the push-button miner. In field tests the performance of the machine was impressive: coal could be extracted at a rate of almost 500,000 tons per year. Under actual mining conditions, however, the push-button miner proved unreliable and could not exceed the performance of conventional augers. Only two of the machines were built, and development was abandoned.

In 1981 a machine with features similar to those of the push-button miner was introduced into the U.S. by Rhine-Schelde-Verolme Machine Fabriken en Scheepswerken N.V., a shipbuilding company in the Netherlands. The machine, known as the Thin-Seam Miner, is designed to mine hillside coal seams from 24 to 63 inches high. The cutting head tracks the coal seam with the aid of sensors that distinguish the differing levels of natural radioactivity in the coal and in the surrounding layers of shale. The reach of the cutting head is increased by the insertion of 20-foot extension beams that allow coal to be mined to a depth of 220 feet.

The manufacturer states that the miner can recover up to 85 percent of the coal within its reach. With a crew of four the machine is said to be capable of mining 420 tons in an eight-hour shift, or 105 tons per man-shift. Several Thin-Seam Miners have been operating in the U.S. since last fall. They are valued at $2.5 million each and are leased rather than sold. In return for royalties on the coal mined the distributor provides a complete service, including installation, operating crew and maintenance.



LONGWALL MINING, which has been common in British and European mines for many years, exploits a continuous mining machine that either planes or shears coal from one face of a block 500 feet wide and up to a mile long. The machine shown is a double-drum shearer. The cutting machine makes continuous passes across the entire face. The mine layout no longer follows a room-and-pillar pattern (except for entryways surrounding the longwall panels). Instead the roof adjacent to the longwall is supported by hydraulic props that move forward as the face is advanced. The roof behind the props is allowed to collapse, leaving rubble called gob. When a panel has been mined out, the cutter and supports are moved to the next panel.

In conventional surface mining the basic sequence of operations—stripping away the overburden and mining the exposed coal seam—has not changed from the beginning. As equipment has grown larger and more powerful it has become economic to mine seams as much as 200 feet below the surface with draglines and excavators whose buckets can hold up to 180 cubic yards of earth and rock. To loosen the overburden drills now sink holes more than 10 inches in diameter to a depth of 75 feet to accept explosives fed in bulk from large trucks. The coal seam is fractured in the same way. The coal itself is scooped up by shovels with a capacity of up to 22 cubic yards and is loaded into trucks that hold up to 170 tons.

Increases in the size of surface-mine equipment are now slowing. Machine improvements are directed instead toward efficiency, reliability and ease of maintenance. Major subassemblies are being made in separate modules to facilitate transport, initial installation and subsequent repair.

Diagnostic tools, equipment monitoring and operator aids have become increasingly important as the cost of fuel and the cost of having machinery out of service for maintenance or repair have mounted. Digital computers have entered mining as they have every other industry. A dragline simulator, for example, has been programmed to teach a new operator the "feel" of the device before he climbs into the cab of the actual machine. Once the operator is at work his skills are improved by a feedback system. An on-board computer provides a visual display of performance and retains a record of machine operation and condition, thereby helping to optimize output and decrease maintenance.

Although most equipment used for

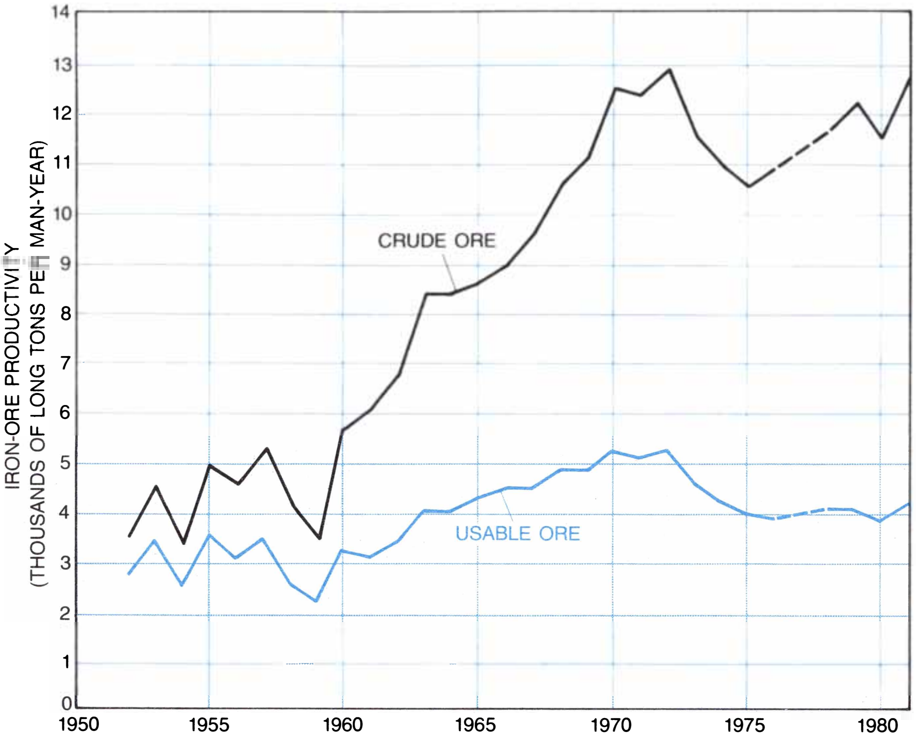
surface coal mining could serve for general excavation and earth-moving work, one machine is highly specialized. It is the bucket-wheel excavator, which holds great promise for efficient extraction of Western coals and Texas lignite that are somewhat lower in energy content than those customarily mined. These huge machines, built in West Germany by O & K Orenstein & Koppel Aktiengesellschaft, have bucket wheels from 7.8 to 15 meters in diameter. They can rapidly remove a large volume of overburden and deposit it several thousand feet away by means of conveyors without the need for truck haulage or other rehandling of the material.

The bucket-wheel excavator makes possible the recovery of seams that lie more than 300 feet below the surface, well below the depths now considered feasible for stripping. In an eight-hour shift the machine can remove as much as 24,000 cubic meters of overburden, the equivalent of a football field excavated to a depth of 15 feet. Although the machines cost from $1.5 to $4 million, depending on their size, they should prove economical for mines that produce two million tons per year or more, particularly if the customer is a nearby electric-power plant. Under such conditions competitively priced electric power could be generated from coals and lignite of low energy value.

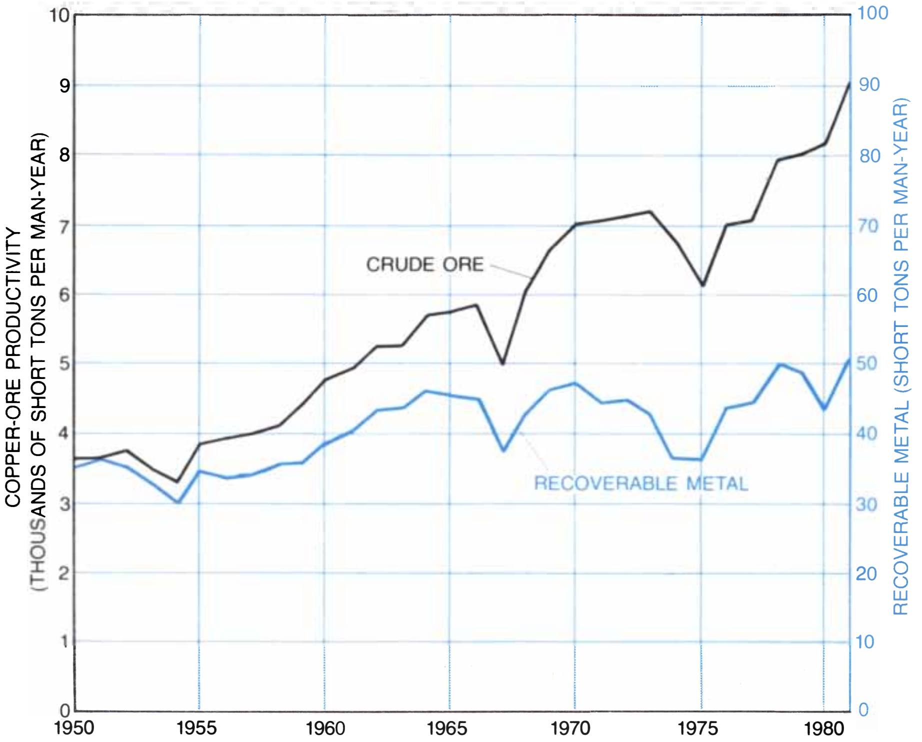
Strip-mine operators are required by Federal and state laws to return mined-out areas to their approximate original contour and to make them fit for their former use. Power requirements for leveling the loose mine wastes are much lower than they are for dislodging the overburden from its original compacted state. The job is done efficiently by large bulldozers. In recent trials two bulldozers have been yoked in tandem, coupled to a single 40-foot blade, and driven by one operator. Once the land has been graded it is reseeded. Power mulchers chop hay and spray it on hillsides to prevent erosion. In many cases aircraft broadcast seed, fertilizer and mulch. It is not unknown for the reclaimed land to have a higher value and higher productivity than it had before stripping.

The surface-mine work force must have skills very different from those of the underground work force. Although functions directly related to the coal itself are generally planned by mining engineers, many of the operators of draglines, shovels, graders, trucks and bulldozers working in surface coal mines have had no mining experience. They have worked instead in other large earth-moving projects.

Over the years the benefits of mine mechanization in raising both the productivity of workers and their income have been offset in part by new hazards introduced by changes in tech-



PRODUCTIVITY IN IRON-ORE MINING between 1952 and 1981 increased at an average rate of 4.5 percent per year calculated on the basis of crude ore mined (*black curve*) but at the much lower rate of 1.5 percent when measured on the basis of usable ore (*color*). Most domestic iron ore comes from surface mines. The 1981 output of 4,180 long tons (4,680 short tons) per man-year of usable ore can be compared with the productivity of 6,700 short tons per man-year in surface coal mining, where productivity has increased at a rate of 2 percent per year.



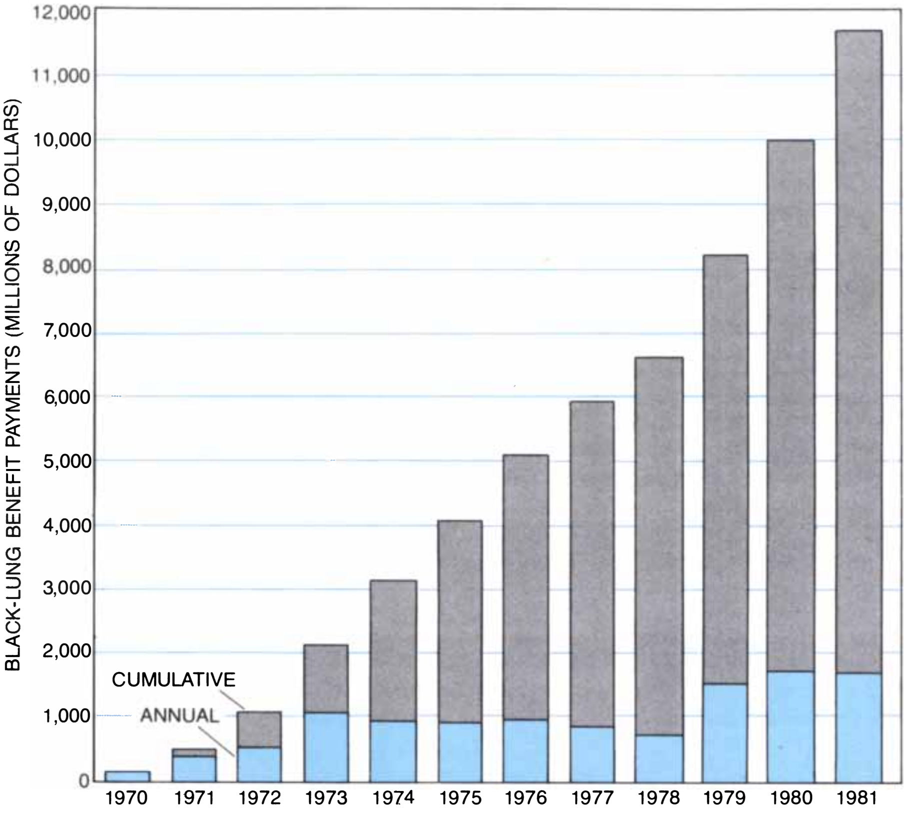
PRODUCTIVITY IN COPPER-ORE MINING between 1950 and 1981 increased at a rate of 3 percent per year on a crude-ore basis (*black curve*) and at a rate of 1.2 percent per year for recoverable metal (*color*). About 85 percent of the copper-ore tonnage is extracted from open-pit mines. In 1950 each ton of copper ore mined contained an average of about 19 pounds of copper. By 1981 the average metal content had dropped to about 11 pounds per ton of ore.

nology. Beginning in 1870, when records were first kept, the number of workers killed in coal-mine accidents in the U.S. initially dropped and then rose. The 1880 fatality rate of 2.2 deaths per 1,000 workers was exceeded in 52 of the next 53 years. Only since 1948 has the fatality rate stayed below two per 1,000, with the exception of 1968, when it again reached 2.2. Even so, the overall trend since 1907 (the worst year of the century, when at least 3,024 miners died in underground-mine accidents) has been downward. Since 1970 the number of coal miners killed has averaged 140 per year, a significant drop.

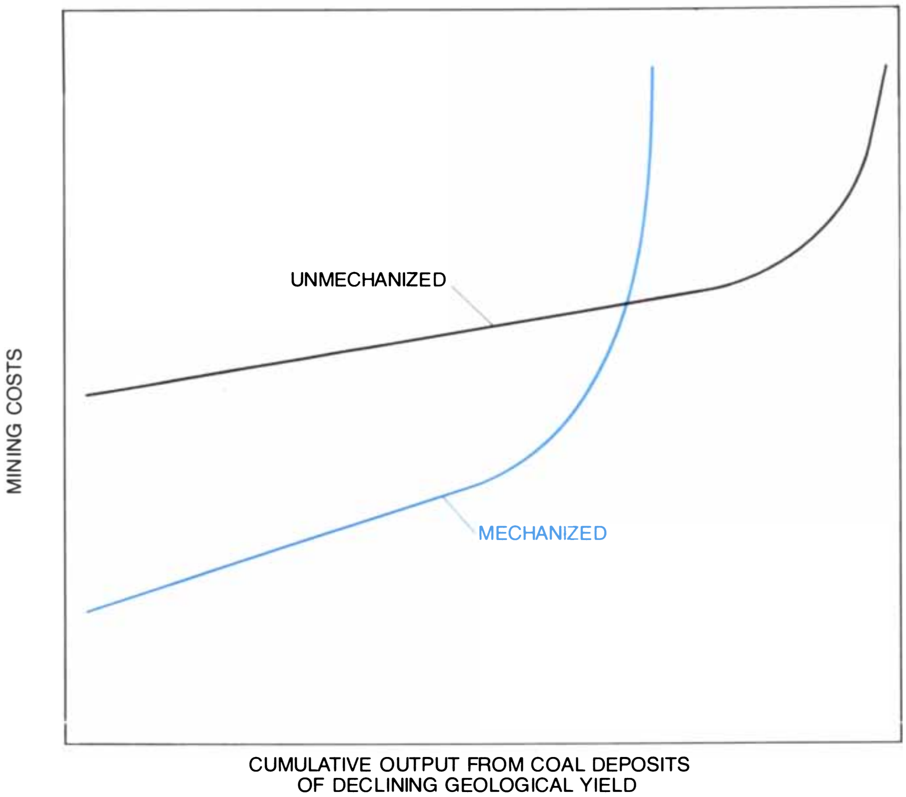
The most serious hazard introduced by mechanization was fine coal dust, which became a problem when the pick was replaced by power machinery for undercutting the coal face. The hazard is increased when methane gas trapped in the coal is liberated as the coal is fractured. When methane is mixed with air in concentrations of from 5 to 15 percent, it is highly explosive. The explosion of a small amount of methane can trigger a much larger explosion of coal dust, or even a series of explosions that might be propagated throughout the mine. Very likely it was such a series of explosions that killed 358 miners in a West Virginia mine in December, 1907, the record number for a single coal-mine disaster.

The first undercutting machines increased the rate of coal fracture and with it the rate of methane liberation. This led to the need for improved ventilation. The problem became worse still with the adoption of continuous mining machines, because the coal not only was cut faster but also was ground into finer particles and more dust. Mining machines are now equipped with methane sensors that shut the units down before the concentration reaches a dangerous level. The cutting is also done under a continuous water spray to hold down dust. The main precaution against dust accumulation, however, is the application of an inert layer of limestone over the walls and roof as mining proceeds.

Much of the mine-safety legislation in the U.S. has been stimulated by mine disasters. Over most of its history the Bureau of Mines has been concerned with the prevention of mine fires and explosions and with improving mine rescue operations. The Federal Coal Mine Health and Safety Act of 1969, and amendments to it enacted in 1977, gave the bureau responsibility for all aspects of mine safety and miners' health. The legislation was precipitated in part by the efforts of the United Mine Workers of America to gain compensation for miners who had developed black-lung disease, a respiratory disease caused by prolonged inhalation of coal dust. Another factor was a series of mine accidents that caused 311 fatalities in 1968,



BENEFITS TO RETIRED MINERS suffering from black-lung disease are financed in part by a levy of 50 cents per ton on surface-mined coal and $1 per ton on coal mined underground. Last year benefits of $600 million were paid from this fund to about 90,000 miners, dependents and survivors. An additional $1.1 billion was paid in the form of Social Security benefits.



STUDY OF MECHANIZATION IN GERMAN COAL MINES has shown that the benefits of mechanization diminish as mining is extended to coal deposits that are less accessible and of lower quality. Eventually the costs per unit of coal extracted in a mechanized mine exceed those in an unmechanized mine exploiting comparable deposits. The diagram is from a report by Gunter B. Fettweis of the University of Mining and Metallurgy in Leoben, Austria.

including an explosion in Farmington, W.Va., that killed 78 miners.

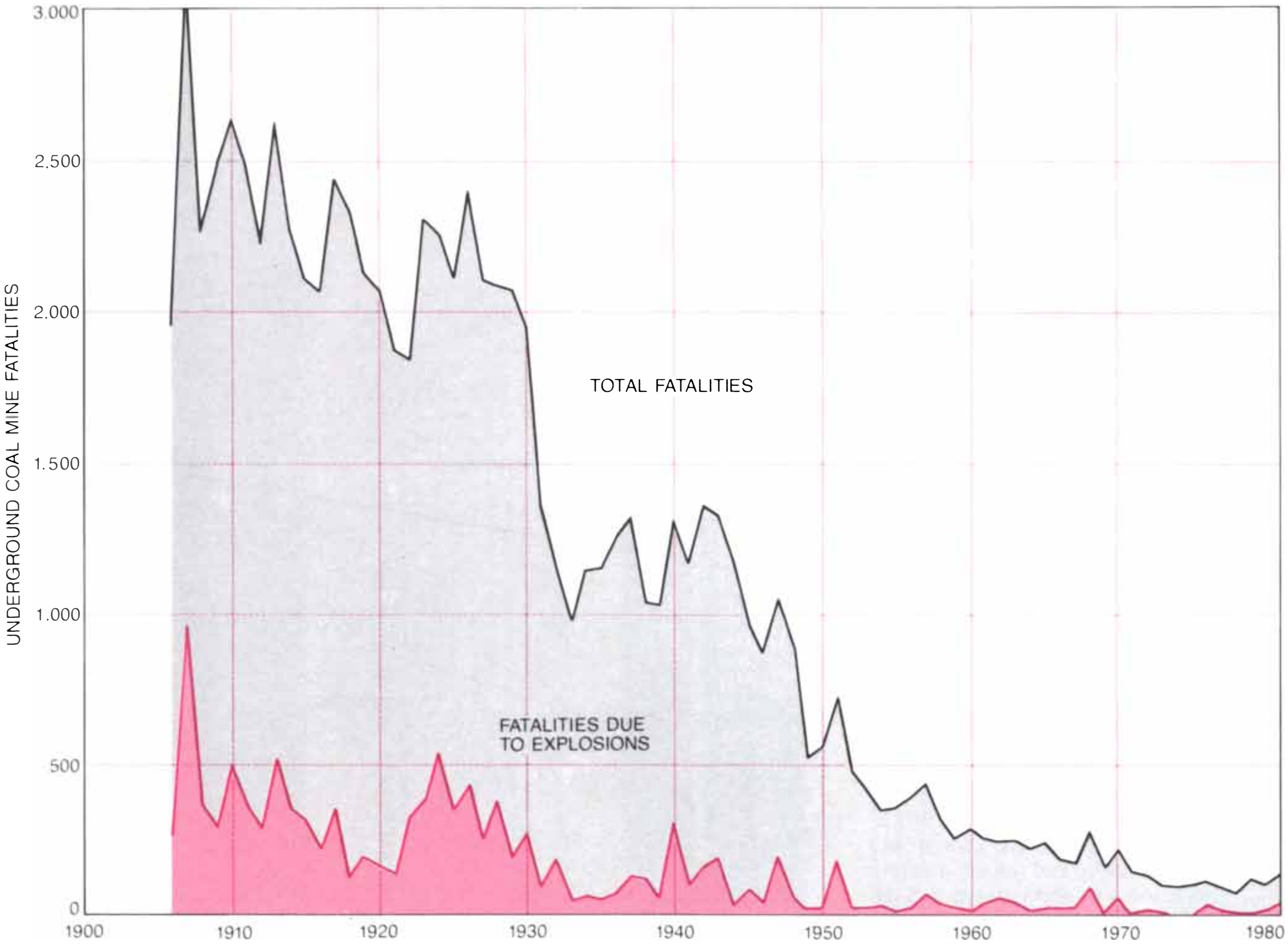
Respirable dust in underground mines continues to be a major health problem, and so does noise. It is well documented that exposure to high noise levels over a long period leads to permanent hearing impairment. The aggregate cost to the miner, his family and society cannot readily be calculated but is certainly substantial. Coal mining, of course, is not the only industry where sustained noise damages the hearing of its workers. Since 1970 the coal industry has made considerable progress in reducing the noise of its machines, above the ground as well as below. So far miners whose hearing has been impaired have not been entitled to compensation in the U.S. In Australia, on the other hand, the number of claims for occupational deafness has risen steeply, reaching 600 in 1979 and 1980.

The U.S. began paying benefits to retired miners with black-lung disease in 1970. In the first five years the cumulative payments amounted to $3.1 billion. In the next five years another $5.1 billion was paid out. To date the program has cost $11.7 billion.

The 1969 Health and Safety Act specifies that the respirable dust in coal mines must not exceed two milligrams per cubic meter of air. Room-and-pillar mines, including those with continuous mining machines, have been able to satisfy the regulation. In longwall mines, however, at any one time about half of the operations are having difficulty complying. The Government and industry have joined forces to solve the problem. In 1970 about 15 percent of underground coal miners exhibited some degree of black-lung disease. The incidence is now down to about 6 percent.

Changes in the technology of mining through the remainder of the century will be evolutionary, as they were in the past, rather than revolutionary. A period of at least 10 to 20 years is needed for a new mining technology to replace an older one. The reasons are the same as those that could be cited in any other industry: the high capital cost of new equipment, the inclination of operators to stick with proved methods and uncertainty about the performance of new devices. A special obstacle to innovation in underground coal mining is that a change in a subsystem, such as haulage, may require a change in the entire mining system. Nevertheless, longwall mining, which requires the most radical change of all, is expected to grow, depending in part on how successfully it can be adapted to thin seams in the East and thick ones in the West.

The future of surface mining will be influenced by changed perceptions of the economies of scale. At some point the operator finds that too much capital has been invested in equipment. The trend to ever larger surface equipment can therefore be expected to slow. Ultimately as operators of surface mines attempt to reach deeper seams they will find their costs approaching the costs of underground mining. Then the half-century decline in underground mining will begin to reverse.



FATALITY RATE IN UNDERGROUND COAL MINES has declined sharply in the past 50 years with improved safety measures. Most fatal accidents in underground mines are caused by roof falls and cave-ins, which regularly took from 1,000 to 1,200 lives per year until 1931, but explosions are dreaded because of their potential for killing many miners in a single accident. Explosions can result when methane released from the fractured coal reaches a dangerous concentration. A methane explosion can trigger explosions of coal dust.

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SCIENCE AND THE CITIZEN

Budgeting Basics

The economic recession, high interest rates and the hundred-billion-dollar deficit in the Federal budget left the scientific community with little hope this year that Federal support for research and development would be spared major cutbacks. As it has turned out, the Government's commitments to science for fiscal year 1983 are more generous than most budget-watchers had expected. Although Congress may alter the allocations somewhat, the total research-and-development budget will probably increase by about 10 percent over fiscal year 1982, rising from $38.8 billion to about $43 billion.

Like the Ford and Carter administrations, the Reagan Administration has earmarked most of the Federal research-and-development budget for work related to national defense. It is probable that Congress will lower the research budget of the Department of Defense, which now amounts to about 57 percent of the total, but military research and development will still remain the largest single expenditure by far.

Again like the two preceding administrations, the Reagan Administration has expressed support for the continued funding of basic research by the Government. A change of emphasis can be perceived, however, in the amounts actually requested in the budget proposal and in the apportionment of the money to the various Government departments and academic disciplines. The earlier administrations asked for real growth each year (meaning an increase even after adjusting for the effects of inflation) in the total Federal support for basic research. The Reagan Administration is seeking a substantial increase (16.6 percent since fiscal year 1981 after discounting for inflation) only for defense-related basic research. A few other areas, such as elementary-particle physics, will get small increases, but the overall budget for basic science will decline by 1.3 percent in constant-value dollars.

Even if basic research has received preferred treatment in the allocation of the budget, the Reagan Administration has been more selective than any previous administration in its sponsorship of basic science. The policy of selectivity was adopted at the urging of George A. Keyworth, science adviser to the president, who stresses that funding decisions should reflect the "distinction between excellence and mediocrity." The fields where excellence is to be found evidently include (besides defense) the physical sciences and engineering, which are given increased allocations.

It should be noted that although the Department of Defense is receiving more than half of the research-and-development budget, only 3 percent of its share goes to basic research. The National Aeronautics and Space Administration, which does some basic research, will probably get a real increase in funding. Basic-science programs that in recent years have been supported by the Department of Energy are also expected to show real growth. (The Department of Energy may be disbanded; its research activities would be taken over by the Department of Commerce.)

Agencies that are traditionally the major supporters of basic research, however, did not fare as well. The National Institutes of Health, which funds the largest number of basic-research projects, will be operating with a real decline of about 7.8 percent in its basic-research funding. The National Science Foundation, whose primary responsibility is the support of basic research, will have about 3.8 percent less to spend on basic research.

In a special analysis of the research-and-development budget the Office of Management and Budget has outlined some of the Administration's priorities and intentions. "The 1983 budget reflects a clearer delineation than has been the case in the past," the analysis states, "between the responsibilities of the Federal Government and those of the private sector with respect to research and development to help meet national needs." In making this delineation the Administration has left much development work to the private sector. What the Government has kept for itself is research and development considered likely to benefit the nation but that private industry is unlikely to invest in because of its long-term nature. For example, in the field of energy technology the Government will continue to sponsor work on fusion power but will leave to others the investigation of conservation and "alternative" sources of energy.

A spokesman for the Office of Management and Budget stated that the Government has properly cut back on energy research and development that "can and should be done by industry." Harold P. Hanson, executive director of the House Committee on Science and Technology, however, considers "largely unrealistic" the idea that private industry will take over the research the Administration has delegated to it. "No corporation looking for short-term profits is ever going to do the long-term projects necessary for the well-being of the nation."

A statement by a senior policy analyst at the Office of Science and Technology Policy suggests that the Administration is aware that some projects may not survive on private funding. "Many things won't be picked up by private industry," the analyst conceded. "The question is: Should things be done at all? The Government was doing research that nobody wanted."

Textual Selection

Last year the Arkansas state legislature passed a law requiring that creationism be taught along with evolution in the public schools. Although a Federal court has ruled that the law is unconstitutional, it appears the influence of the creationist doctrine is being felt elsewhere: in high school textbooks. The inroads of creationism came to light recently in a decision by the Board of Education of New York City. The board ruled that three current biology texts are unfit for use in the city schools because of inadequacies in their treatment of the concepts of evolution.

The three rejected textbooks are *Experiences in Biology,* published by Laidlaw Brothers; *Life Science,* published by Prentice-Hall, Inc., and *Natural Science: Bridging the Gap,* published by the Burgess Publishing Company. The Laidlaw book discusses evolutionary concepts but omits any mention of the word "evolution" or of Darwin. According to officials, the other books treat evolution superficially; moreover, they show a credulous attitude toward the theory of divine creation. One passage from the Burgess text cited in the decision reads: "Another hypothesis about the creation of the universe with all its life forms is special creation, which gives God the critical role in creation. In some school systems it is mandated that the evolution and special-creation theories be taught side by side. That seems a healthy attitude in view of the tenuous nature of hypothesis."

The "healthy attitude" that would require creationism and evolution to be presented on an equal footing in biology courses was held in the Arkansas case to violate the separation of church and state established by the First Amendment to the Constitution. The ruling was made in January by Judge William Overton in response to a suit filed by the American Civil Liberties Union challenging the Arkansas Balanced Treatment for Creation Science and Evolution Science Act. A similar statute was passed in Louisiana in 1981; the ACLU has also brought suit there. Legislation with similar aims is pending in a number of other states.

Although the central place of evolution in the teaching of biology has been upheld in the courts, some observers think the effect of the legal controversies is to make publishers wary of textbooks that might offend creationists.

Robert M. May of Princeton University wrote recently in *Nature*: "Even as the community of professional biologists takes comfort from Judge Overton's incisive and unequivocal verdict against the state of Arkansas' law mandating equal time for 'creation science' in the biology classroom, there are signs that new editions of major high school biology texts are being eviscerated."

For publishers the problem is most serious in the 22 states where textbooks must be approved by a state board. The states, mainly in the South and West, include Texas (which has an annual budget of $45 million for textbooks) and California (which represents 10 percent of the U.S. market for textbooks). "Given the highly competitive nature of the textbook market, the pressures that this system—with all its political and populist overtones—puts on publishers is obvious," May concludes.

The current situation is similar in certain respects to that of the late 1920's, when fundamentalist religious groups campaigned to eliminate the teaching of evolution from the schools. The case of John T. Scopes in 1925 was a notable victory for the evolutionist position, but other efforts of the fundamentalists that attracted less attention were more successful. According to May, "the real battles were being fought over state and local decisions about which textbooks to adopt for high school biology courses and here creationists advanced on a broad front throughout the 1920's and 1930's."

Indeed, many of the biology texts that had included discussions of evolution in the early 1920's eliminated all reference to the subject in editions published after 1925. Dorothy Nelkin of Cornell University observes in *Science Textbook Controversies and the Politics of Equal Time* that "a scholarly survey of the content of biology texts up to 1960 found the influence of antievolutionist sentiment to be persistent, if undramatic, and showed that the teaching of evolution actually declined after 1925." Nelkin adds that "by the late 1930's some publishers were tentatively introducing evolution but most, discouraged about market prospects and anxious to avoid controversy, avoided the topic."

Safety in Numbers

Shortly after George B. Dantzig of Stanford University had invented the simplex algorithm, a mathematical method of allocating scarce resources in an optimum way, he reportedly told his colleagues not to worry about its slowness. The algorithm was proposed, he said, only to demonstrate that certain resource-allocation problems could be solved in principle; a more efficient method would soon be forthcoming. There was no need to worry, his colleagues replied. The algorithm had already been applied to several enormous problems and it had delivered solutions as promptly as anyone could want.

Thus was born a celebrated puzzle of more than 30 years' standing, which is arguably the most important problem in applied mathematics: Why does the simplex algorithm work so much better in practice than it ought to in principle? Now Stephen Smale of the University of California at Berkeley has taken a major step toward settling the question. He has demonstrated that the simplex algorithm can indeed be expected to yield an optimum solution in a short time. The results are still under review, but mathematicians so far praise the work highly; it has been submitted for publication in *Mathematical Programming*.

The simplex algorithm has enormous economic importance in government and industry. The algorithm determines the most profitable or least expensive course of action under a number of constraints. It is applied extensively in petroleum refining, papermaking, food distribution, agriculture, steelmaking and metalworking (see "The Allocation of Resources by Linear Programming," by Robert G. Bland; SCIENTIFIC AMERICAN, June, 1981).

Suppose a paper company makes 50 grades of paper, each grade requiring different quantities of wood pulp, chemical sizing, bleach and clay coating. If the company devoted production exclusively to its most profitable grade of paper (white bond, say), the supply of bleach might be exhausted long before the other resources were used up. Indeed, if at least some bleach is needed for all grades of paper, the allocation of all the bleach to the production of white bond would halt the manufacture of the other grades in spite of ample inventories of the remaining resources. The task of maximizing the paper company's return on its investment in the various resources is one of determining just how to allocate the resources most effectively to the entire range of products.

In principle the best allocation can be found by calculating the profit expected from every feasible program, or plan, of production. In almost all practical circumstances each feasible production program can be represented by one of the infinite number of points that lie on or within a polytope, the analogue of a polygon in many dimensions. It turns out that to find the most profitable program it is necessary to check only the vertexes of the polytope. The number of vertexes is finite, but even in a routine problem it can be enormous. B. Curtis Eaves of Stanford estimates that for the problem of allocating 2,000 limited resources to 2,000 products, the number of vertexes of the polytope is on the order of $2^{2,000}$, or about 10^{602}. Yet such problems are solved many times a day, Eaves notes, because the simplex algorithm can generally find the optimum vertex among the 10^{602} vertexes by examining only about 6,000 of them.

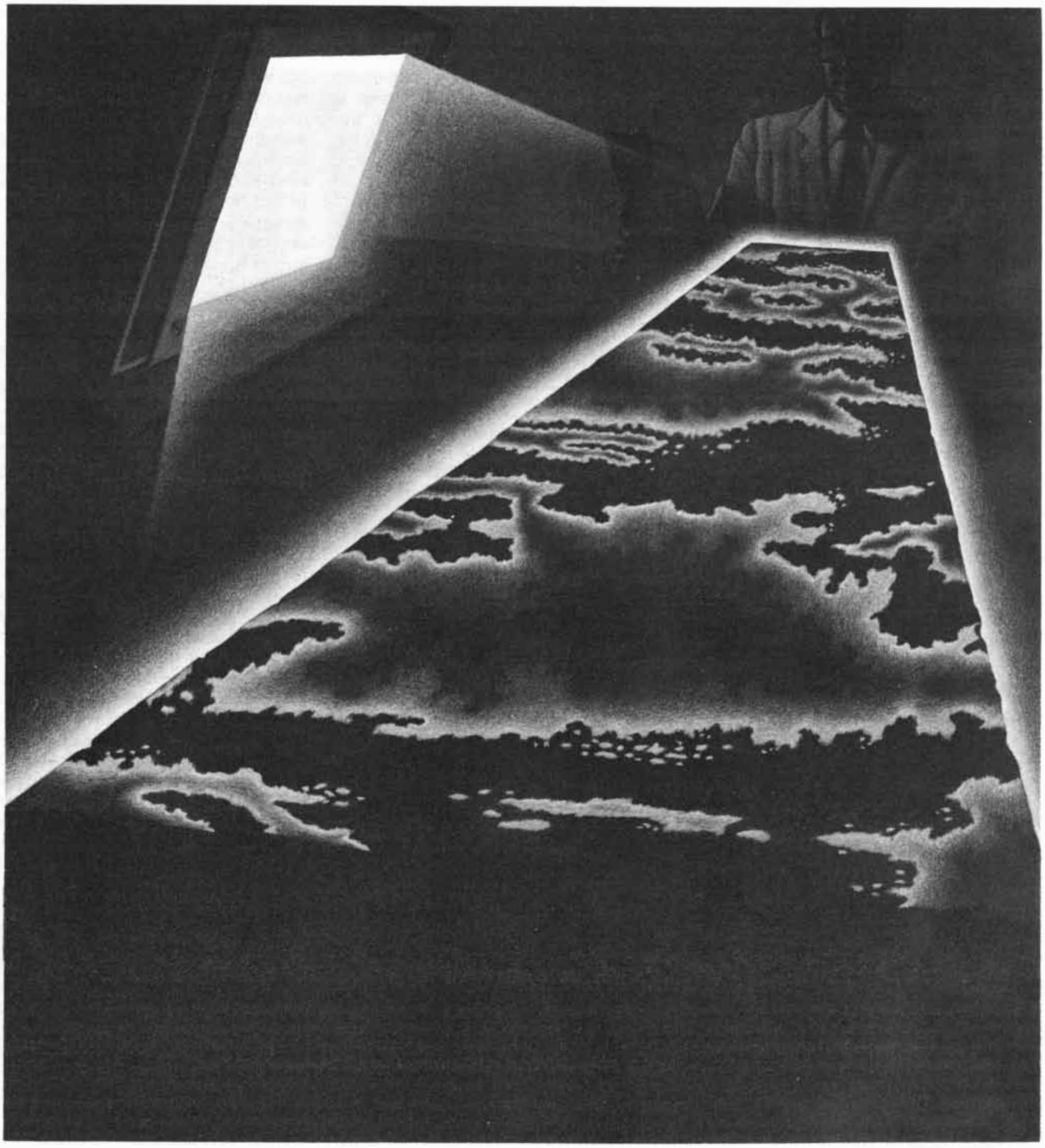
What Smale has shown is that there is an upper bound to the expected number of vertexes that must be checked by the simplex algorithm. Smale's upper bound is a complicated function of the size of the problem, where the size is defined by the number of constraints and products. For the example given by Eaves, Smale's bound is larger than 6,000 vertexes, but it is considerably smaller than 10^{602}. As the problems become larger Smale's upper bound grows more slowly. Hence, although he has not fully explained why the algorithm has performed as well as it has, he has shown that for extremely large problems the expected number of vertexes investigated is even smaller than the number given by a rule of thumb now widely used by mathematicians.

Smale's bound is not a guarantee that the simplex algorithm will always work rapidly; the bound is a probabilistic one, although it should apply to the great majority of cases. Several years ago Victor La Rue Klee, Jr., of the University of Washington and George J. Minty, Jr., of Indiana University constructed a family of problems in which the simplex algorithm investigates almost every vertex of a polytope before it finds the optimum solution. Smale's work shows that such problems are very rare; indeed, not one has turned up in more than 30 years of practical problem solving. Smale's analysis may make it possible to explain why the simplex algorithm fails when it is applied to the problems devised by Klee and Minty.

All the tRNA in China

The ribonucleic acid tRNA (short for transfer RNA), a key molecule in the translation of the genetic code into specific protein structures, has been directly synthesized for the first time by a team of biochemists in the People's Republic of China. The construction of the tRNA replica reportedly took years of effort by a large number of workers and yielded only an exceedingly small quantity of the substance: a few nanomoles. The synthesis was crowned by a laboratory test showing that the replica is capable of biological activity.

In the living cell tRNA molecules act as individualized escorts for amino acids, the subunits of proteins. There are 20 kinds of tRNA, and each kind conveys one of the 20 common amino acids to the site where a protein chain is being assembled. The tRNA molecule itself is made up of nucleosides, the components of all nucleic acids. Four standard nucleosides (adenosine, guanosine, uridine and cytidine) are represented in all forms of RNA, but tRNA is distinguished in addition by a comparatively large number of chemically modified nucleosides, which are rare in other nu-



cleic acids. The tRNA molecule is a single chain less than 100 nucleosides long. The chain is folded back on itself and fastened together by hydrogen bonds to form a characteristic pattern of single-strand loops and double-strand stems that is commonly represented in two dimensions as a cloverleaf.

The exact sequence of nucleosides in a yeast tRNA specific for the amino acid alanine was deciphered in 1965 by Robert W. Holley and his colleagues at Cornell University. A decade later two independent groups of investigators, one group at the Massachusetts Institute of Technology and the other at the British Medical Research Council Laboratory of Molecular Biology in Cambridge, determined the three-dimensional structure of yeast phenylalanine tRNA. At about the same time H. Gobind Khorana of M.I.T. announced that he had synthesized the gene for yeast alanine tRNA, thereby opening the way to the indirect production of variants of the molecule through the manipulation of DNA sequences.

Meanwhile the Chinese group had set out on a different project: the direct synthesis of a replica of yeast alanine tRNA, starting with organic chemicals and enzymes. The undertaking began in the late 1960's but was interrupted for a number of years by the turmoil attending the "cultural revolution." Work was resumed in 1977 and eventually demanded the efforts of almost 200 investigators from a number of institutions in both Shanghai and Beijing. The project was carried out under the direction of Wang Debao of the Shanghai Institute of Biochemistry of the Chinese Academy of Sciences; a specialist in nucleic acids, Wang had studied biochemistry in the U.S. and was at one time associated with Johns Hopkins University.

According to a recent interview with Wang, published in *Chemical and Engineering News,* the first order of business was to prepare the raw materials: not only the four major nucleosides but also seven minor ones (1-methylguanosine, 5,6-dihydrouridine, *N,N*-dimethylguanosine, inosine, 1-methylinosine, pseudouridine and ribothymidine), as well as various reagents and enzymes. All the materials, Wang said, had to be made "from scratch" by members of the group.

The assembly of the 76-nucleoside molecule of yeast alanine tRNA then proceeded in stages. Small bits of the molecule, consisting of between two and eight nucleosides, were made and then linked into six larger pieces. Next the pieces were joined to form two half molecules and finally the halves were combined to create the complete molecule. The synthetic tRNA was shown to be biologically active by exposing it to the appropriate amino acid (alanine) and then following the amino acid as it was incorporated into a protein.

Although the amount of tRNA produced was small, Wang commented, the large amounts of comparatively rare ingredients assembled by the Chinese group should make it feasible to undertake a systematic investigation of how changes in the chemical structure of a tRNA molecule affect its biological activity. The Chinese investigators, it was suggested, will be looking with particular interest at the roles played by the modified nucleosides in the functioning of tRNA.

The Excited Pion

With the proliferation of "exotic" elementary particles the pion, or pi meson, has come to seem rather prosaic. It was predicted to exist in 1935 and was first observed in 1947; now pions are made by the hundred billion in particle accelerators. Nevertheless, the pion is in some respects more difficult to understand than the rarer exotic particles. Evidence of excited states of the pion has only recently been reported.

In the modern view the pion, like all other mesons, is a composite system made up of a quark and an antiquark. The pion is the lightest such system, with a mass (in energy units) of about 140 megaelectron volts, or MeV, which is roughly a seventh the mass of the proton. Various "flavors," or basic kinds, of quark and antiquark can combine to yield different mesons. Furthermore, the properties of a meson depend not only on the flavor of the quarks but also on their mode of motion. For example, the pion itself is the state of matter in which the lightest quark and antiquark are bound together in their lowest-energy mode of motion. In this mode the intrinsic spin angular momenta of the quark and the antiquark cancel and there is no orbital angular momentum, so that the meson has a total angular momentum of zero.

For certain mesons made up of a much heavier quark and antiquark a rich spectrum of excited states has been observed. The best example is the particle designated *J* or psi, which was discovered in 1974; the first excited state was found a few days later, and roughly a dozen related mesons are now listed in the catalogue. All the states have the same quark constituents, but they differ in energy, angular momentum and other properties because in each state the quark and antiquark have a different mode of motion.

The pion should have a similar spectrum, but the excited states have proved quite difficult to detect. The recent evidence is reported in *Physical Review Letters* by 15 investigators from the Italian national institutes of nuclear physics in Milan and Bologna and the Joint Institute for Nuclear Research at Dubna in the U.S.S.R. The investigators employed a beam of high-energy pions generated by the proton accelerator at Serpukhov, 60 miles south of Moscow. They examined 120,000 events in which a pion collided with an atomic nucleus and gave rise to three pions.

Earlier experiments by other workers had hinted at the possibility of pion excitations, but the results were uncertain and inconsistent. The recent experiments at Serpukhov revealed a broad enhancement in the number of three-pion events at an energy of 1,240 MeV, indicating the existence of a particle with that mass. A second enhancement was found at 1,770 MeV. Both enhancements seem to signal the presence of a meson in which the spin angular momenta of the quark and the antiquark cancel and in which there is no orbital angular momentum; in other words, the angular momentum of the two new mesons is the same as that of the pion. Certain other properties of the new mesons have also been shown to be identical with those of the pion. "These observations can be interpreted as radial excitations of the pi meson," the report states. In a radial excitation the trajectories of the quark and the antiquark have the same shape as those in the pion itself, but they extend over a larger volume.

Lucy's Lineage

Seven skull fragments found last year in the valley of the Awash River in Ethiopia extend the age of *Australopithecus,* the earliest hominid known, to the middle Pliocene, at least four million years ago. The discovery was one of several important fossil finds in this desolate part of the Afar Triangle made during a two-month reconnaissance by an international team headed by J. Desmond Clark of the University of California at Berkeley. The finder of the skull fragments was Leonard Krishtalka of the Carnegie Museum in Pittsburgh.

The fragments were uncovered about 40 feet below a volcanic marker layer known as the Cindery Tuff. Minerals from the tuff have been dated radiometrically by Robert Walter of the University of Toronto. His preliminary finding, based on the decay of a radioactive isotope of potassium and on an analysis of tracks left by the fissioning of atomic nuclei, gives the tuff an age of 4.0 million years, with an uncertainty of plus or minus 10,000 years. Because the skull fragments lay substantially below the tuff they are presumed to be older still.

Until the recent discoveries the oldest hominid specimen known was "Lucy," a remarkably intact representative of the genus *Australopithecus* discovered in the mid-1970's by Donald C. Johanson, then at Case Western Reserve University. "Lucy" was found some 45 miles north of the Awash River site and was assigned by Johanson to a new species, *A. afarensis.* The fossilized skeleton is thought to be 3.6 million years old.

The Awash River skull fragments are

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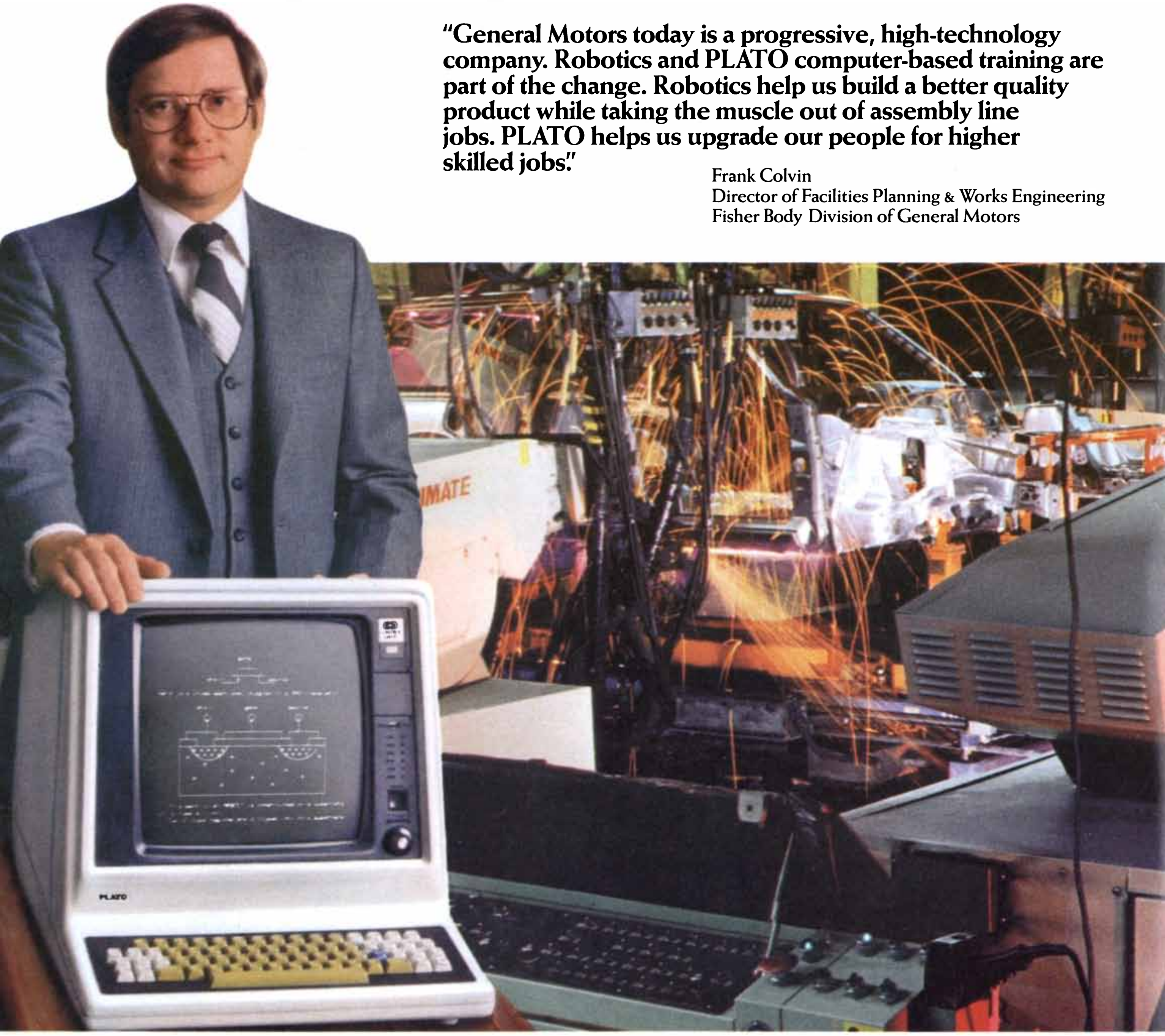

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from the frontal bone of an individual assigned by the team's paleontologist, Tim D. White of Berkeley, to the same species as "Lucy." A portion of the suture where the frontal bone meets the parietal bone is present, enabling White to determine that the individual was an adult. The frontal bone is extremely primitive in form and is slightly smaller than that of the average chimpanzee.

At a point 20 feet above the Cindery Tuff, White found the upper part of an *Australopithecus* femur, or thighbone, belonging to an adult fully adapted to upright walking. White estimates that the individual stood about four feet six inches tall. This fossil has also been assigned to the species *A. afarensis*. Because the femur is somewhat later than the skull fragments, its presence in the same area suggests that the extinct hominid species inhabited the valley of the Awash River for a considerable span. The two finds also provide further evidence that bipedal locomotion was an established hominid attribute long before the evolutionary changes that led to the enlargement of the hominid skull.

Ocean Tomography

A large-scale analogue of the clinical technique that makes maps of planes through the human body is beginning to map patterns of temperature, salinity and density in the sea. The clinical technique is computer-aided tomography, or CAT scanning. It relies on sending X rays through the body along a variety of paths. On each path the ray encounters tissues of differing density and hence is attenuated by a particular amount. The data representing the attenuations have hidden in them the spatial pattern of the tissue, and by a mathematical procedure (the inversion of a matrix) the pattern can be recovered.

The new oceanographic technique is termed acoustic tomography. It differs from CAT scanning in that the signals employed to probe the sea are low-frequency sounds rather than electromagnetic waves. It differs also in that information is extracted from the signals not by measuring their attenuation but by recording their arrival times at submerged receivers. The speed of sound in seawater varies in direct proportion to both pressure and temperature. With increasing depth the pressure increases but temperature tends to decrease, and so the two trends have countervailing effects on the speed of sound. Measurements made at progressively greater depth show that the speed decreases to a minimum and then starts increasing again. For example, in the sea southwest of Bermuda at a latitude of 26 degrees north the speed of sound falls to a minimum value of about 1,490 meters per second at a depth of about 1,100 meters.

Sound waves broadcast close to the depth of this minimum follow oscillating trajectories through the sea. The waves are refracted upward when they stray downward and downward when they stray upward, alternately ascending and descending through thousands of meters of ocean depth. In effect the sound waves are repeatedly deflected as they pass between mediums that differ in index of refraction. (The same phenomenon traps a beam of light in an optical fiber.) Thus a given receiver in the sea can detect a succession of signals from a single distant burst of sound because the signals travel at different velocities along paths of different lengths. Along any such path the sound may have passed through an eddy of warm or cold water, altering the transit time. The various delays therefore have hidden in them the pattern of the eddies.

Last year a group including Ted Birdsall of the University of Michigan, Walter Munk and Peter Worcester of the Scripps Institution of Oceanography, Carl Wunsch of the Massachusetts Institute of Technology and Robert C. Spindel of the Woods Hole Oceanographic Institution deployed acoustic instruments in the Atlantic Ocean southwest of Bermuda. A square of the sea 300 kilometers on a side was chosen for the test. Four transmitters were installed along the eastern edge and four receivers along the western edge; a fifth receiver was placed on the northern edge. All the instruments were at a depth of 2,000 meters.

Twenty horizontal paths linked the transmitters to the receivers. The oscillatory trajectories that sound waves take in the sea made it possible to monitor three or four times as many paths. Furthermore, the passage of the signals through a great range of depths allowed three-dimensional maps to be constructed from the data. In one method of analysis the 300-kilometer square is divided into smaller volumes. The analysis gives a speed of sound for the center of each volume. The speed of sound in turn gives a temperature, and the temperature corresponds to a certain salinity. The depth at the center of the volume implies a certain pressure, and so the density can also be inferred.

The investigators find that their tomographic survey southwest of Bermuda is in agreement with the measurements they made there by lowering instruments such as temperature sensors from a ship. It therefore appears that tomographic "snapshots" of a large expanse of the sea are feasible. Writing in *Oceanus,* Spindel notes that conventional oceanographic instruments "yield information only at a single point," so that a survey of a 300-kilometer square of ocean takes "about three weeks." A tomographic mapping takes minutes. Moreover, in the conventional three-week survey "the image is smeared or blurred much the way a photograph blurs when the subject moves because during the course of a survey the ocean circulatory pattern changes."

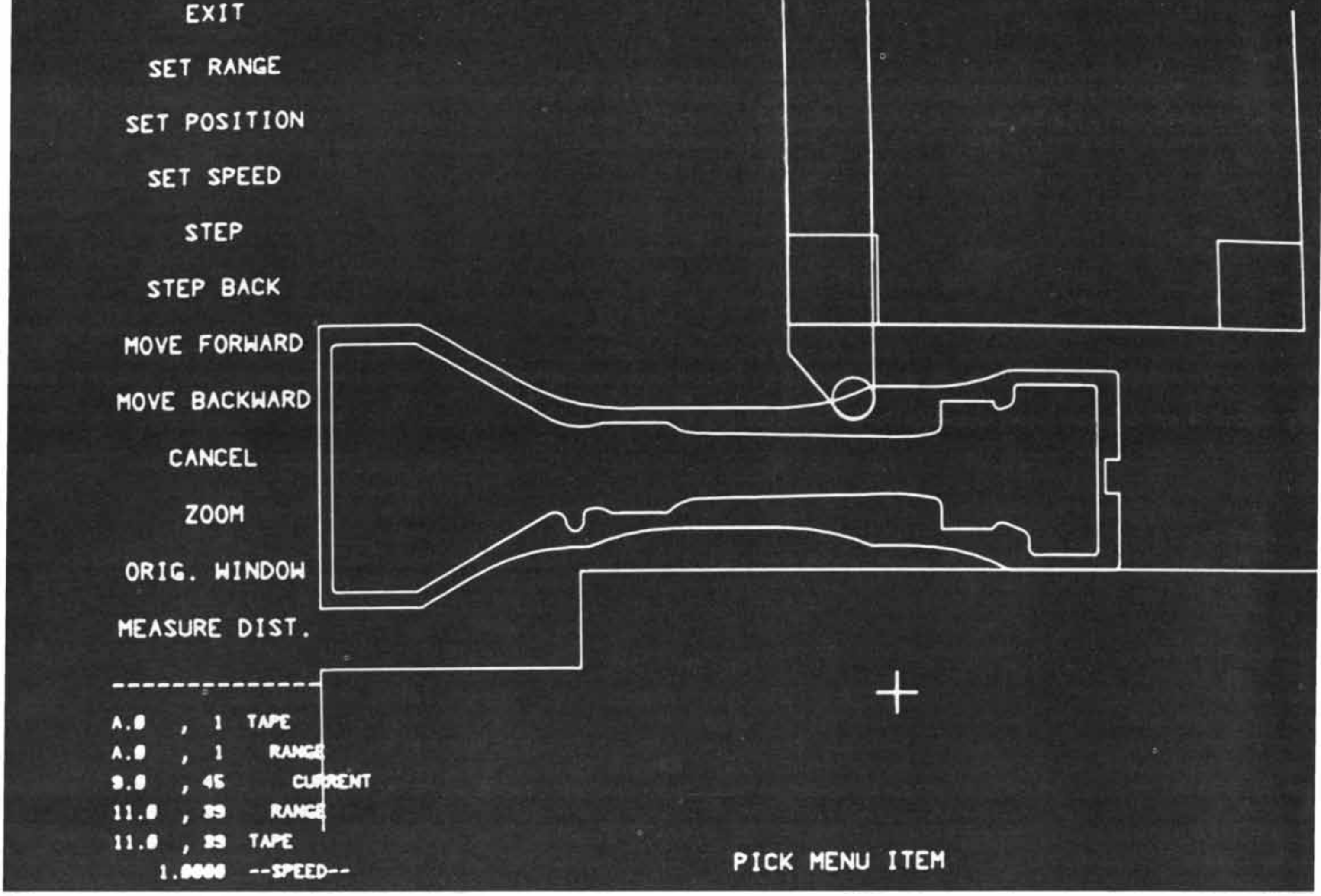
The investigators hope next to develop and deploy networks of devices that simultaneously transmit acoustic signals and receive them. The intent is to measure differences in transit time for signals passing in opposite directions between pairs of instruments. Such differences would result solely from the circulatory pattern; hence a tomographic snapshot could survey not only temperature, salinity and density but also ocean currents. One prospect is to plot on a single grand map the rotational current at a given moment throughout a large basin such as the Sargasso Sea.

Audible Radar

The notion that some people can tune in radio transmissions without a receiver is probably as old as broadcasting. Since the invention of radar during World War II, however, it has been known that some people can indeed hear microwave signals. The phenomenon seems implausible. Radar operates at frequencies of from 300 megahertz to 300 gigahertz, far outside the range of normal human hearing (from 20 hertz to 15,000 hertz). Furthermore, the mechanism that actuates the ear is a pressure wave, whereas the radar signal is an electromagnetic wave. Now three workers who have reviewed a long series of experiments and hypotheses on radio-frequency hearing report in *The Journal of the Acoustical Society of America* their conclusion that the phenomenon is caused by thermoelastic expansion.

The investigators are Chung-Kwang Chou and Arthur W. Guy of the School of Medicine and College of Engineering of the University of Washington and Robert Galambos of the School of Medicine of the University of California at San Diego. They set out to review work done on radio-frequency hearing since 1956. Some of the investigations were psychological. The first people to report hearing radar, they note, "encountered skepticism and rather pointed questions about their mental health." Physiological and behavioral observations of animals have also contributed to understanding, and so have physical measurements of materials. The experimenters found "uniform agreement that human beings with normal high-frequency hearing can perceive an auditory sensation when exposed to microwave pulses of sufficient energy content." The sound "may be perceived as clicks, buzzes or hisses."

What happens, the investigators report, is that the absorption of microwave energy causes a nonuniform heating of the head. A thermoelastic wave of pressure is thereby launched and is conducted, presumably by bone, to the cochlea, the sensory organ of the inner ear, where it is detected.



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PICK MENU ITEM
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The Mechanization of Design and Manufacturing

Mechanization on the factory floor continues, but greater changes are being introduced by new technology for the design of products and for planning, managing and coordinating their manufacture

by Thomas G. Gunn

The factory is the workplace where mechanization might seem to be most deeply embedded. Indeed, the origin of the modern factory can be traced to the introduction of water-powered and steam-powered machinery in the 19th century, most notably in the textile industry. Today the typical factory relies on a great variety of machines, and factory work is widely supposed to consist largely of tending machines. Newer developments in the relations between men and machines also tend to be viewed primarily in the context of manufacturing, and the social consequences of mechanization have been considered chiefly through their effects on production workers. There is an irony here: it turns out that manufacturing is one of the most difficult sectors of the economy in which to realize the full potential of the available technology.

The opportunities for mechanization in the factory are widely misunderstood. The emphasis has been almost exclusively on the production process itself, and complete mechanization has come to be symbolized by the industrial robot, a machine designed to replace the production worker one for one. Actually the direct work of making or assembling a product is not where mechanization is now likely to have the greatest effect. Direct labor accounts for only 10 to 25 percent of the cost of manufacturing, and workers engaged in such tasks make up only two-thirds of the total manufacturing work force. The major challenge now, and the major opportunity for improved productivity, is in organizing, scheduling and managing the total manufacturing enterprise, from product design to fabrication, distribution and field service. The complexity of the modern factory is daunting: in some plants thousands of parts must be kept in stock for hundreds of products. Indeed, the complexity of the operations has sometimes led to a situation resembling gridlock on the factory floor: it is not uncommon for a metal part to spend 95 percent of the time required for its manufacture waiting in line for processing.

Thus the productivity of the factory worker depends in large measure on the design of the product and on the way the resources of labor, machines and raw materials are brought together. Without improvement in these functions it is not clear that even a total replacement of blue-collar workers by robots would have much effect on the output of the factory or on the cost of its products. For this reason the most important contribution to the productivity of the factory offered by new data-processing technology is its capacity to link design, management and manufacturing into a network of commonly available information. The social outcome of the linkage may be to alter far more white-collar jobs than blue-collar ones.

In the U.S., companies whose primary business is manufacturing employ some 20 million people, or roughly a fifth of the labor force. The proportion has been declining for the past 40 years, partly because of the shift of the American economy away from the production of goods and toward the production of services and partly because of the technological displacement of workers.

Manufacturing includes a vast array of activities and enterprises. In some industries a product is made in a continuous stream; familiar examples are petroleum refining, papermaking and the manufacture of many chemicals. A distinctive feature of such processes is the ease with which they can be adapted to control by closed-loop feedback systems: changes in the nature of the product can be detected and employed to adjust the input of raw materials or the intermediate steps in manufacturing. Other process industries, such as steelmaking and brewing, generally work with batches of materials.

Here I shall focus on industries of another kind: those that design and manufacture discrete products rather than materials that are processed continuously or in batches. Discrete-products manufacturing is a broad and varied category. It encompasses the fabrication and assembly of automobiles, aircraft, computers and the microelectronic components of computers, furniture, appli-

COMPUTATIONAL LINK between design and manufacturing is illustrated by a system employed by the General Electric Company to control the cutting path of a vertical turret lathe as it shapes a component of an aircraft engine. In the upper photograph two cross sections passing through the radial axis of the disk-shaped part are shown on the screen of a computer-aided-design terminal. The outer cross section shows the shape of the forged part before it is machined; the inner cross section shows the final shape of the part. Above the cross sections the cutting tool of the lathe is represented schematically in one of the positions it assumes while making the cut. The path of the cutting tool is controlled by a computer program; the programmer, who must know the precise geometry of the part in order to program the cutting tool, can retrieve the information from a central data base where it is stored during the design of the part. The path of the tool is then animated on the screen so that the programmer can verify that the cut will proceed as intended and without interference. The lower photograph shows the real cutting tool in a position corresponding to the one simulated on the computer terminal. To make the cut the disk is rotated on a turntable under the cutting tool, which is moved up, down and across the disk according to the pattern determined by the computer program. The disk is made of a titanium alloy and is part of the high-pressure compressor of the CF6-50 turbofan engine. The engine powers a number of commercial and military jet aircraft, including the Boeing 747 and the McDonnell Douglas DC-10; it delivers a thrust of 50,000 pounds.

ances, foods, clothing, packaging, building materials and machine tools. It is in these industries and the many like them that the potential benefits of data-processing technology are most pronounced. Only in the past 20 years has the discrete-products manufacturer had the means to gain feedback from his operations (and hence continuous control over them) by methods analogous to those of the process manufacturer.

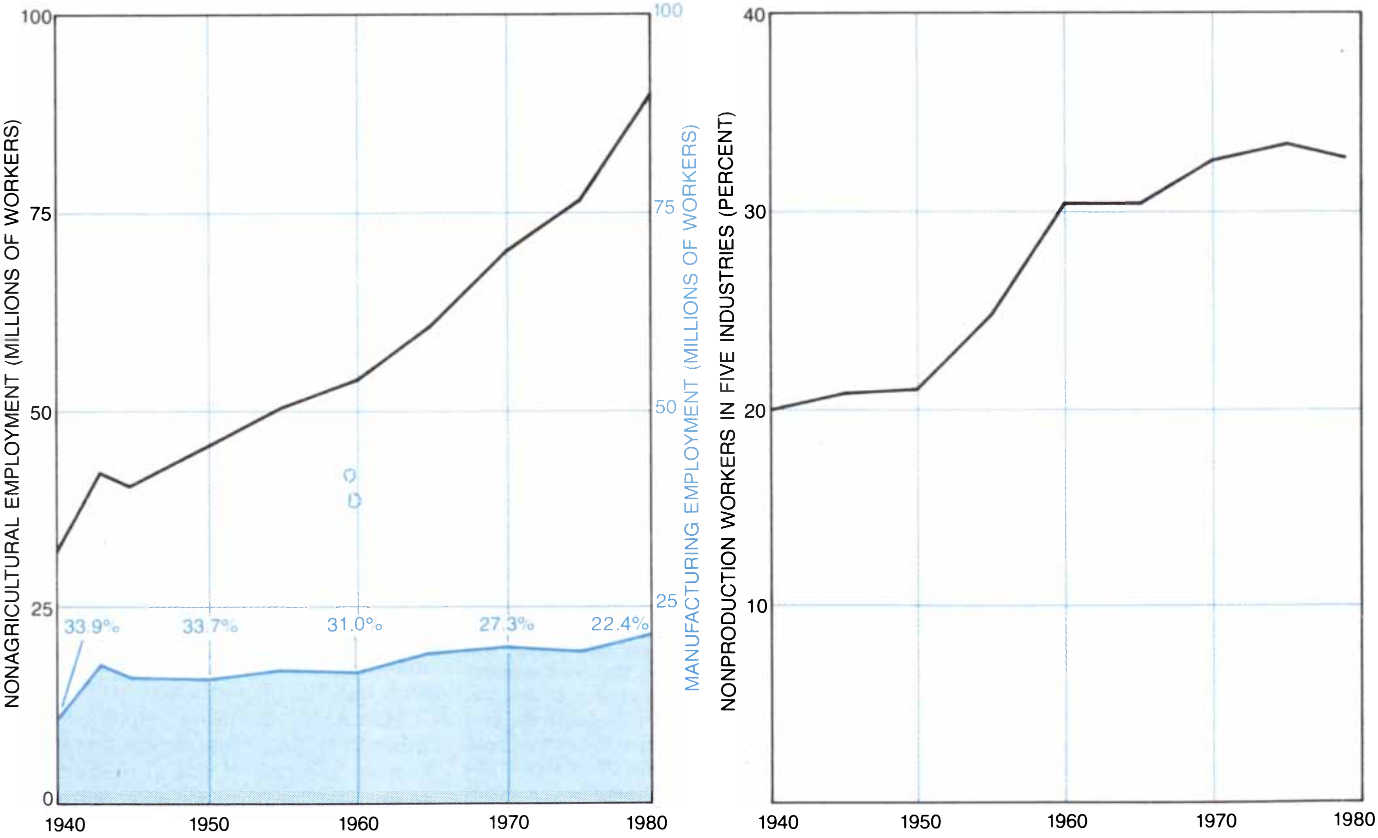
An example of a discrete-products factory I shall frequently refer to is the machine shop. There metal parts are made by a sequence of operations, including cutting, boring, milling, grinding and turning on a lathe. The same set of machine tools can serve to make a great variety of parts, from gun barrels to camshafts; what changes is the sequence of operations carried out with each tool and the sequence of tools employed. The very versatility of the tools makes the efficient organization of machine-shop operations difficult. Methods of programming, or numerically controlling, the machine tools themselves were introduced some time ago and have been widely adopted. The emphasis now is on coordinating the operations of various machines and controlling the flow of work through the shop.

Over the years manufacturers have sought to plan, control and carry out complex operations by setting up large bureaucracies with many levels of responsibility. In some American companies there are as many as 14 layers of personnel in the chain of command from the chief executive officer to the lowest-ranking shop-floor worker. The hierarchical structure enables a company's management to direct the overall operations of the company, but the organizational distance between the top and the bottom makes it difficult to keep close track of labor and plant resources, to schedule their deployment and to control job priorities. Moreover, a hierarchy can give rise to institutional barriers between departments and can inhibit the internal flow of information. It can also create a competitive "us against them" attitude among departments that hinders the functioning of the organization as a whole.

The organizational barriers to communication are often supplemented by physical ones. Written and verbally transmitted information is subject to delay, error and misunderstanding as it passes from one person to another. The time required for a memorandum to circulate can make prompt collective action impossible. As a result large manufacturing organizations have responded sluggishly to changing market conditions. Another consequence of impediments to communication is a need to stock large inventories of products, parts and materials at considerable cost in space, insurance and handling.

By the 1950's the burden of paperwork and verbal communication in many manufacturing concerns had become onerous. In order to get work done on time the companies began to employ expediters who operated independently of the organizational hierarchy to push products out the factory door.

Manufacturing companies were introduced to the computer in the early 1960's. The first applications were the recording of routine financial transactions, but gradually computers were applied to other tasks, such as the control of inventory, the scheduling of production and the routing of a part from one process to another on the factory floor. As the applications diversified and various departments of the company adapted the computer to their needs it became apparent that the advantages of computing technology within each department could be multiplied many times if



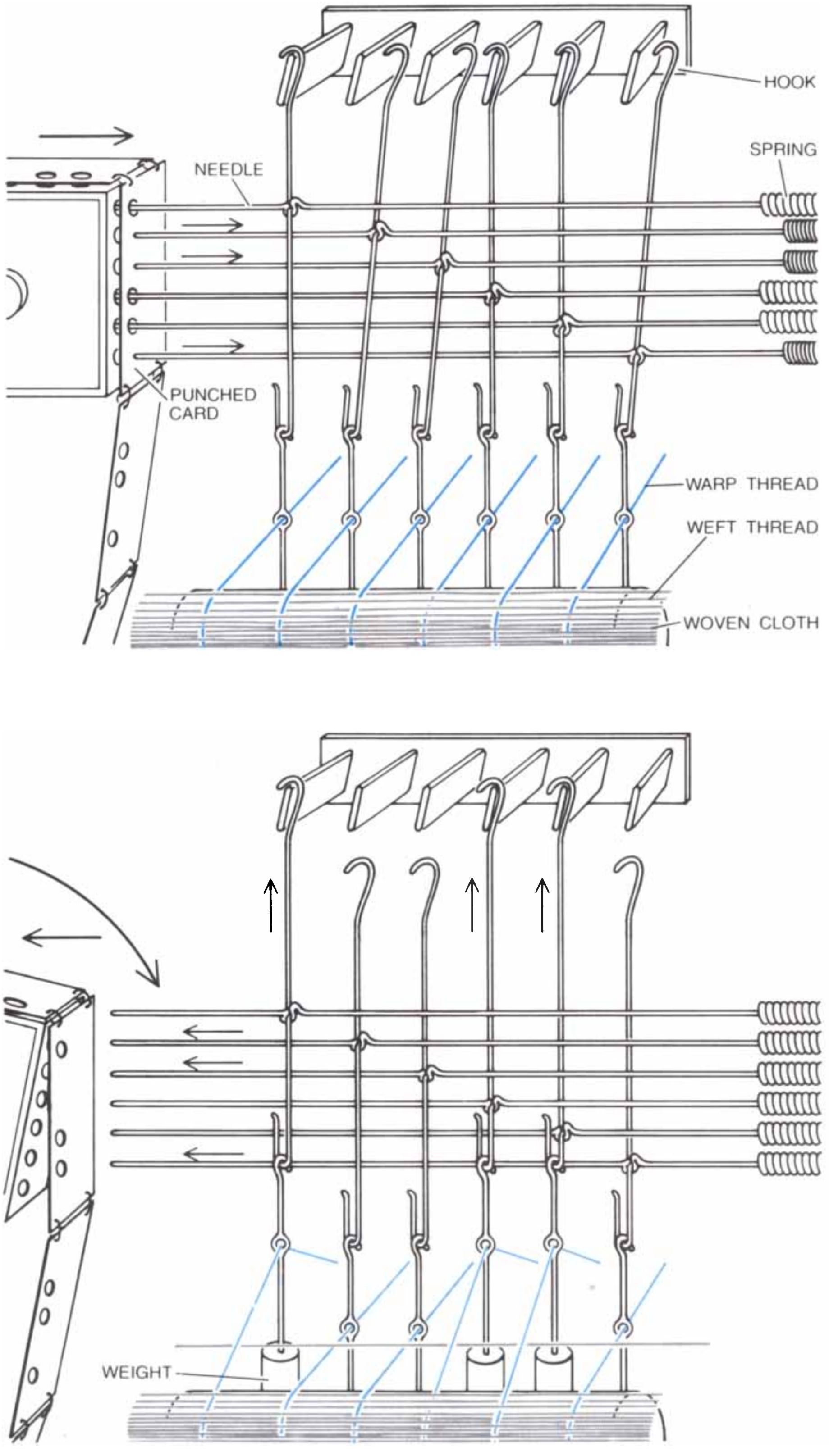
FRACTION OF MANUFACTURING WORKERS in the U.S. engaged in indirect labor (such as planners, expediters, salesmen, managers and the like) has increased even as the manufacturing fraction of the work force has been reduced. There are now about 20 million workers in manufacturing, or 22 percent of the total number of employees on nonagricultural payrolls. In the five most highly mechanized industries, namely fabricated metal products, machinery, electric and electronic equipment, transportation equipment and instruments and related products, workers who supply direct labor currently account for only about two-thirds of the total work force.

certain departments or functions were linked.

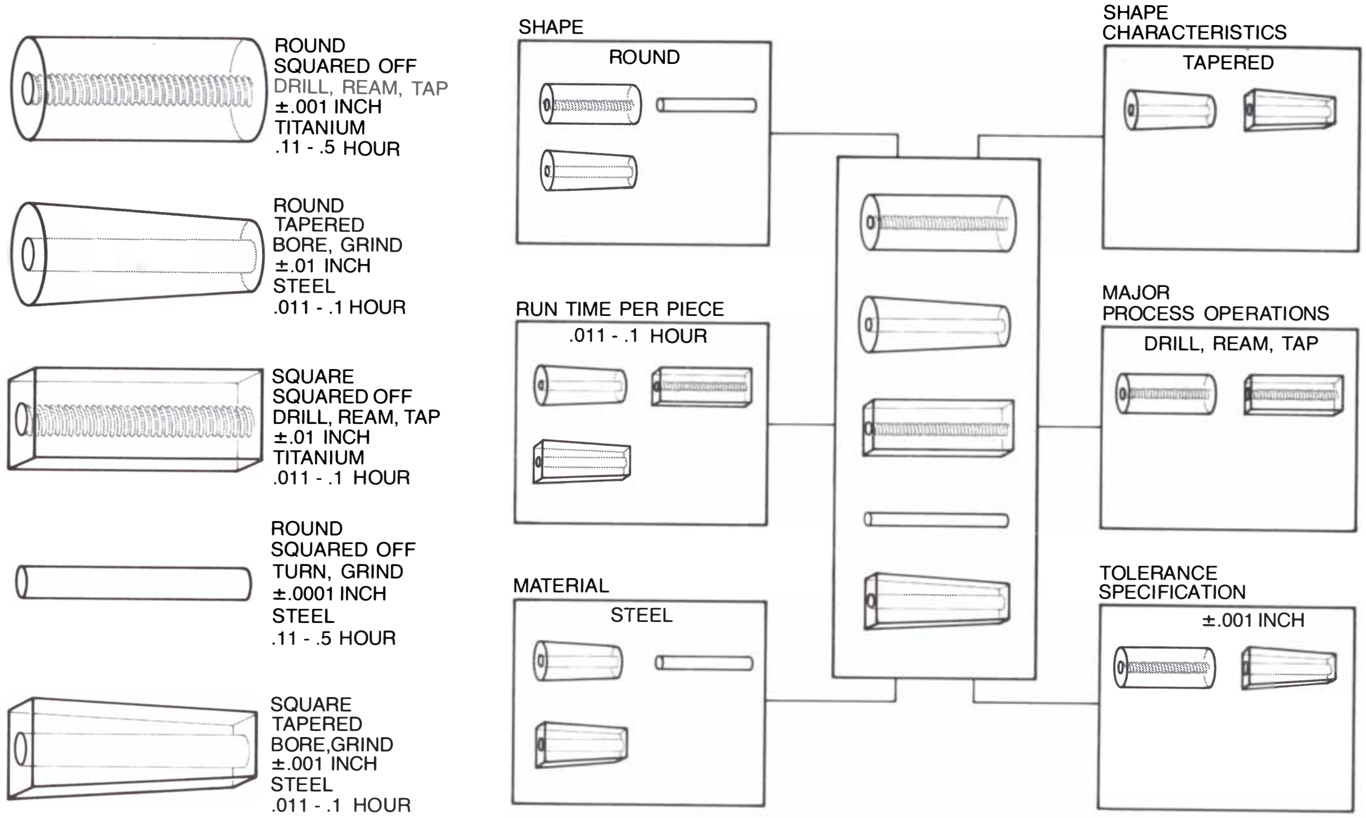
The earliest functions of the computer that had a direct bearing on manufacturing operations were not in the manufacturing process itself but in the design of products. In the mid-1960's engineers at the General Motors Corporation began working with programming specialists at the International Business Machines Corporation to develop a system for computer-aided design. The system was originally envisioned only as a sophisticated drafting tool. The design engineer would employ a keyboard to specify certain numerical data about the part, but he could touch a light-sensitive stylus directly to the screen of a cathode-ray tube in order to "draw," or enter geometric data into the computer. Although the motion of the stylus on the screen might correspond only roughly to the shape of the part, the computer was programmed to combine the numerical and the geometric data so that the designer's sketch could be transformed rapidly into a precise engineering drawing. Because the drawing was stored in the memory of the computer it could be recalled at any time.

The information specifying the geometry of a part is also needed to determine how a cutting machine, such as a lathe, must be operated to shape the part. (The specification of a cutting path must also take into account the capacity of the cutting machine, the material from which the part is made, the shape of the cutting tool, the speed and depth of the cut and other variables.) Traditionally the machinist set up his machine according to drawings supplied by the designer; when numerically controlled machine tools were introduced, the programmer who prepared the sequence of instructions still obtained geometric information from drawings. Designers and programmers soon recognized, however, that the programmer could get the part geometry directly from the data base after it was entered into a computer by the designer, and engineering drawings could be eliminated. Indeed, in many circumstances the programming of machine-tool operations is so routine that little human intervention is necessary once the part geometry is known.

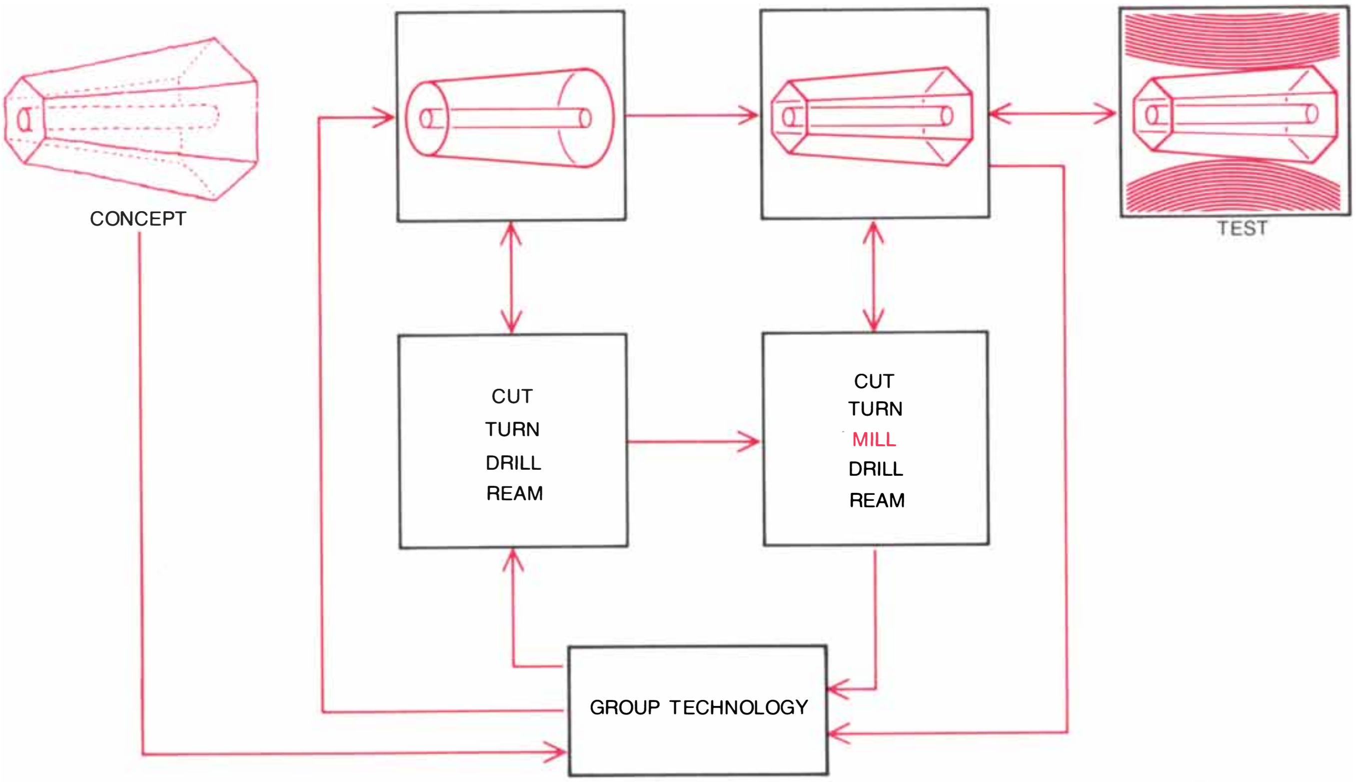
The need for similar information in designing a part and in programming a machine tool to make it illustrates another important contribution that computerized information links can make to manufacturing productivity. Before the advent of computers information pertaining to a product was often scattered in various departments of a company. The engineering drawings, for example, carried certain descriptive information about a product as well as its geometry, but details about how the



JACQUARD LOOM was the first practical industrial machine to be controlled by a stored program of operations; the program was encoded in an array of holes punched in a series of cards. The Jacquard loom was the forerunner of the numerically controlled machine tool, which carries out instructions encoded as holes punched in a paper tape. On the loom the pattern of the weave is ingeniously made to correspond to the pattern of the holes on the cards. A row of needles mechanically connected to the warp, or lengthwise, threads probes each row of holes. If a needle engages a hole, the corresponding thread is raised during the next operating cycle and so appears on the upper surface of the fabric. If the needle does not engage a hole, the thread remains in place and passes to the underside of the fabric. The programming cards enable the machine to execute a complex sequence of motions automatically, and they allow the sequence to be altered conveniently by changing the pattern of holes. The device was invented for the silk industry by the French weaver Joseph-Marie Charles Jacquard in 1801.



BENEFITS OF MECHANIZATION in the factory can result from more efficient management of information as well as from the automatic control of production machinery. Group technology is an electronic filing system whereby the names of all the parts made by a manufacturing company are stored with a list of descriptive characteristics of each part. The parts are cross-referenced by characteristics such as shape, material and processing operations, and so a list of all the parts that have given characteristics can be generated. Group technology can eliminate the wasteful design of a new part whenever it identifies a part already made that will serve the same purpose.



SIMPLIFIED DESIGN and process planning are made possible by group technology. If a new part is needed, the designer can search the inventory of old parts stored in the electronic group file according to the characteristics specified for the new part. For example, if the designer wants a part that is tapered, squared off at the ends, made of steel and bored through along the radial axis, the file might retrieve a bored, truncated conical part already being manufactured, together with the processing steps in its fabrication. The designer can then modify the old design and process plan to create the new part without starting from scratch. The new design can be tested with the help of a computer program to meet engineering specifications; the design and process plan are then stored in the group-technology file.

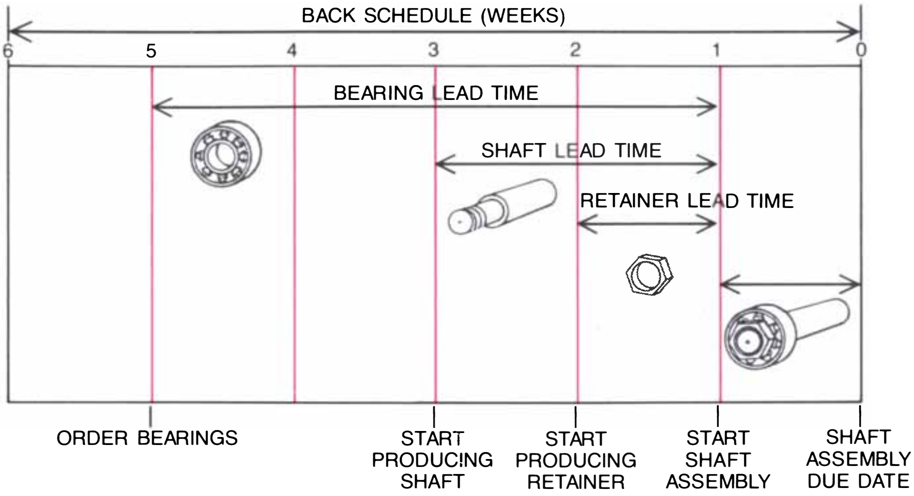
product was to be manufactured, what machines were to be used and when the product was scheduled for processing on a particular machine were kept only by the department responsible for that aspect of production. Much of the scattered information was redundant, and its distribution created difficulties in keeping it accurate and up-to-date.

My colleagues and I have identified six functional areas that are now being linked to manage the flow of information throughout a factory. The areas are design, the storage and retrieval of information about the parts being manufactured, the management and control of available resources (such as labor, machines and materials) according to changing demands, the handling of materials, the control of machine tools and other single-purpose machinery and the control of robots. By linking the six areas one can achieve what Joseph Harrington, Jr., of Arthur D. Little, Inc., has called computer-integrated manufacturing. It is important to realize, however, that data-processing technology must be fairly well developed in each of the areas before the benefits of linking them become significant.

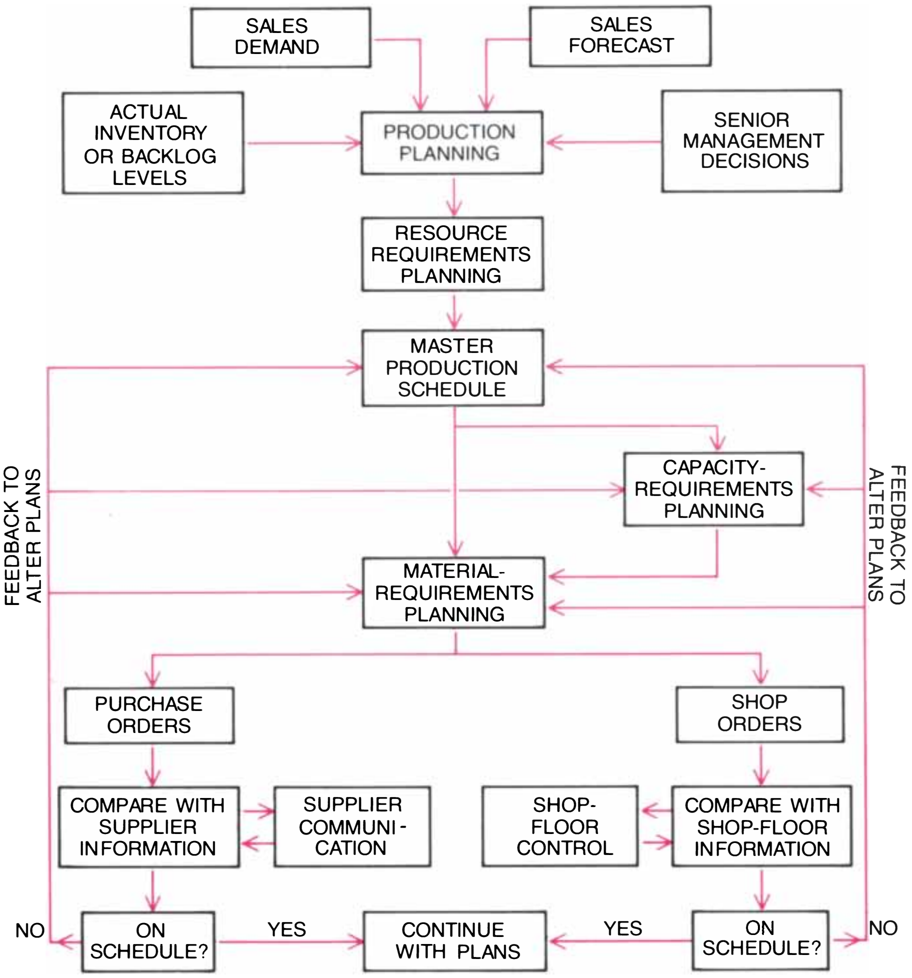
Perhaps the most remarkable instance of growth in productivity as a result of information technology is in the design of parts and production processes. Computer-aided-design programs can carry out geometric transformations so fast that the designer is no longer limited to the top, side and front views of a part that were characteristic of manually prepared drawings. He can observe the rotation of the part about any axis on the screen, "zoom" in close to see details or take up a distant point of view to visualize the object as a whole. Any cross section of the part can be displayed. If the part is to be mated with other parts during assembly, the designer can move the parts about on his screen to check for fit. Hence many prototypes and engineering models can be eliminated.

The image displayed on the screen can be stored permanently in the data on a magnetic tape or disk. If a copy on paper is needed, it can be generated quickly with a plotting device driven by the computer. Because the design is simple to alter in electronic form it can be changed as many times as necessary without the major effort of redrawing. The design is accessible to everyone who must work with it as soon as it is electronically filed, so that manufacturing functions such as the planning and scheduling of production can be started earlier. Because alterations are made only to the centrally filed design there is less chance that someone will work with an outdated version.

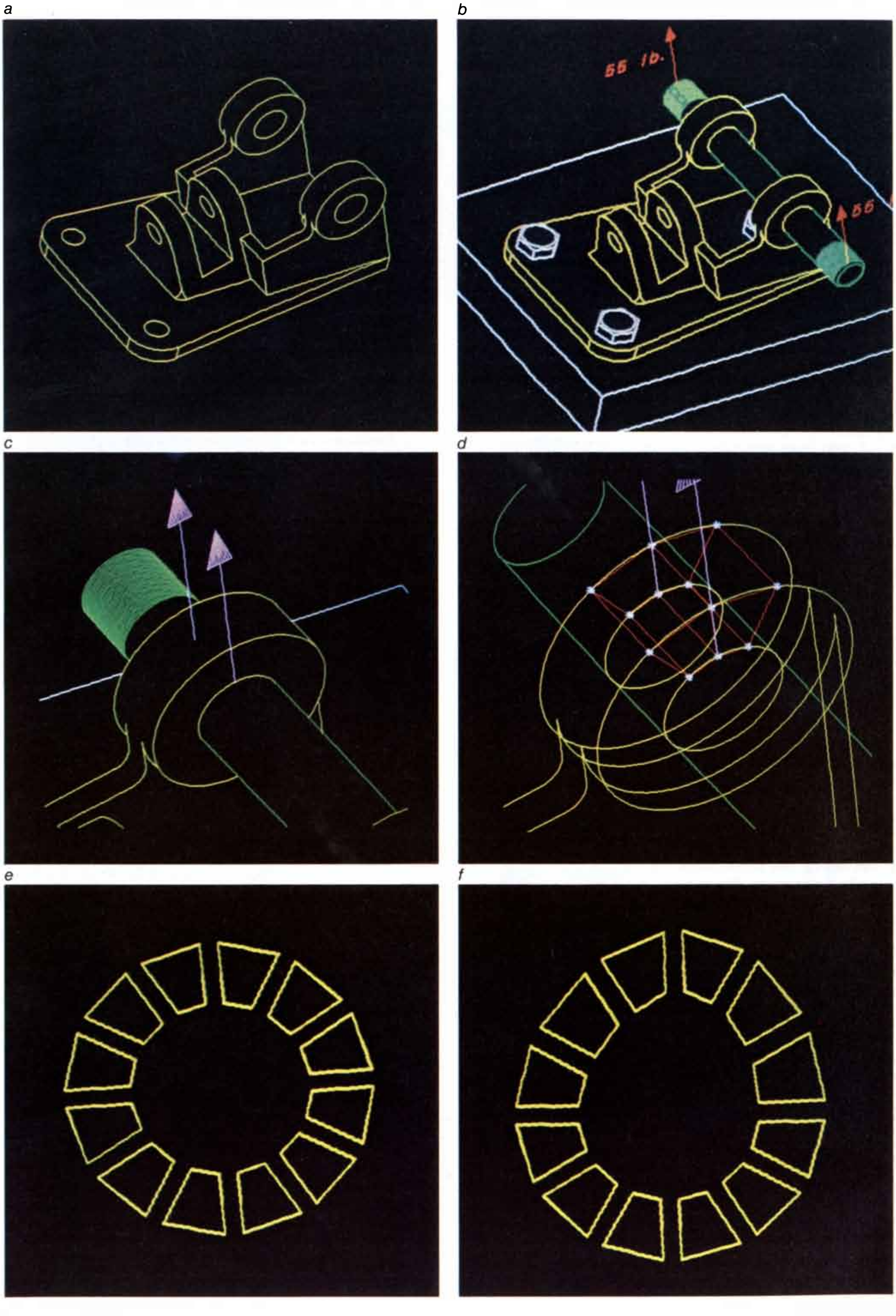
The ready accessibility of the design throughout the company tends to break down the institutional barriers between



BACK-SCHEDULING from the date a finished product is needed must be done in order to determine when the component parts must be manufactured or bought from suppliers. If the component is ready on the date it is needed and not before, the expenses associated with maintaining an inventory of parts (such as insurance, warehousing and the cost of capital) can largely be eliminated. To reduce inventory without causing delays, however, the back-scheduling must be thorough and accurate. The illustration shows how back-scheduling might be accomplished for a part made up of three components. Accurate back-scheduling depends on careful analysis of the lead time and manufacturing time for each part and on an accurate inventory.



MANUFACTURING RESOURCE PLANNING is a more complex form of back-scheduling, in which inventory, demand, a sales forecast and the priorities of management are all taken into account to generate a master production schedule. A computer can then generate detailed production schedules for thousands of parts, materials and processing needs. The success of the system depends on fast and accurate feedback on the status of parts, materials and other resources that must meet the back-scheduled deadlines in order to conform to the master schedule. The flow chart indicates the ideal flow of information in such a planning system.


a
b
55 lb.
55
c
d
e
f

the design and the manufacturing departments. Because the part can be viewed in any orientation, at any scale and in any cross section the intent of the designer is much clearer than it is in a three-view drawing. In return one of the most important benefits to the designer is that an engineering analysis can be done quickly enough for several alternative design solutions to be tried. Engineers can analyze the part for its response to various kinds of stress without building a model or a prototype.

The engineering analysis is also done with the aid of a computer at a cathode-ray-tube terminal. In one method, called finite-element analysis, the part is divided into many small elements, or cells, and the response of each element to stress is observed on the screen. For example, the computer can generate an image of the part as it would look if it were deformed by mechanical stress, showing where the weaker regions are found. Other properties that vary with position, such as thermal and electrical conductivity, can be indicated with a color code for each cell.

The application of computer-aided design generally improves productivity in the drafting room by a factor of three or more, and it has brought striking overall benefits to manufacturers. At General Motors, for example, the redesign of a single automobile model required 14 months instead of the usual 24. Another company reduced the time needed to design custom valves from six months to one month. A manufacturer of molds for plastic parts was able to increase its output from 30 mold cavities per year to 140, solely because of the increased efficiency afforded by a computerized design system. Furthermore, the greatest savings that result from computer-aided-design systems are often effected during the assembly of the final product: the higher quality of the component parts makes the assembly faster and easier.

The information stored in a computer that specifies the geometric design of a part and the stages in its manufacture need not be limited to the part for which it was originally intended. In order to design a new part and plan how it will progress through the factory it is convenient to refer to a design and a process that are already established for a similar part. The need to identify such parts quickly can be met by a rationalized system for the storage and retrieval of information about parts, a system called group technology.

Group technology is in effect an electronic card file listing every part a company manufactures, together with a system for sorting the cards according to various characteristics of the parts. The parts can be classified in any way the company considers useful; generally parts are coded for such physical characteristics as size, shape, volume and materials used and for such manufacturing-process characteristics as the time required for the setup of the machinery, the machining sequence and the number of parts ordinarily made in a single lot. Once the parts have been classified the process planner for a new part can retrieve a list of old parts that have some of the same characteristics. He can then plan for the production of the new part simply by specifying that the manufacturing process is to be the same as that for the old part, with any differences noted. The procedure is called variant process planning.

The labor savings made possible by group technology is remarkable. Analysis has shown that in many companies only 20 percent of the parts initially thought to require new designs actually need them; of the remaining new parts 40 percent could be built from an existing design and the other 40 percent could be created by modifying an existing design.

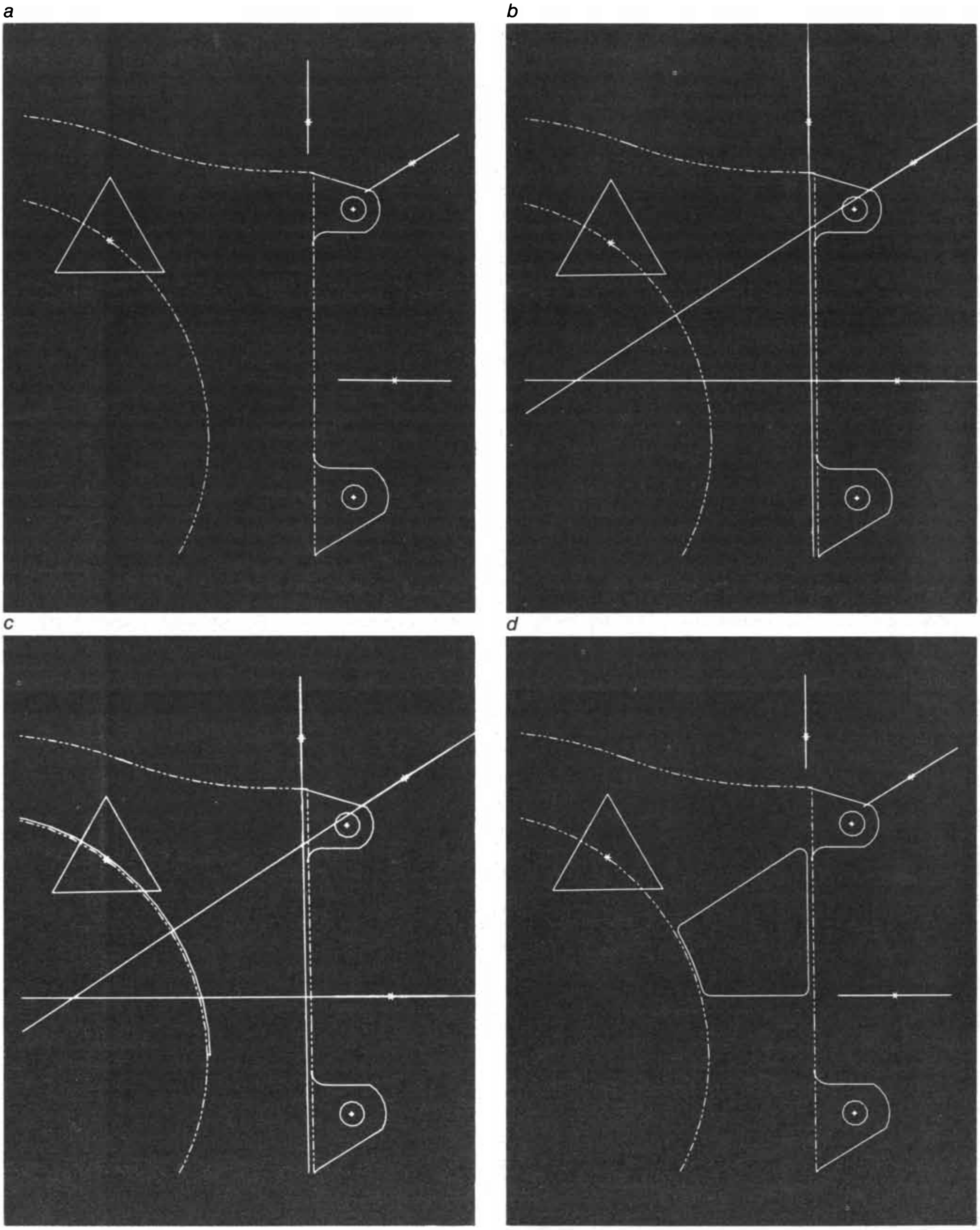
Group technology can be applied not only to planning but also to the production machines themselves. Production machines can be grouped according to the parts for which they are employed; they can also be sorted into small cells of machines, each cell being dedicated to the production of a single family of parts. The regrouping allows a higher production rate and a more efficient use of the machinery.

Allocating the resources of a factory to maximize profits or productivity would be an exceedingly difficult mathematical problem. The methods of queuing theory and linear programming would have to be applied to a situation in which there may be hundreds of machines and workers, thousands of potential products and an almost unlimited number of routes a given product might follow during production. In the factory today, however, the practical problem is not to determine the best-possible configuration of labor, machines and products. Typically the organization of production is so far from the mathematical optimum that even a clearly suboptimal solution may offer substantial improvement. The immediate need is for a relatively simple method of planning and control that can cut down on long waiting times and eliminate most of the costs associated with inventory.

There are now several ways the computer can assist in planning and control. The simplest method is called manufacturing resource planning, which seeks to predict the demand for each element in the manufacturing process at a given time. For example, a manufacturing-resource-planning program could indicate how many milling machines (and how many operators for the machines) are needed in a factory making several products that call for milling. The method is an outgrowth of a system introduced by IBM in 1968 for determining when certain materials are needed in manufacturing. The basic idea of manufacturing resource planning is that the scheduling of labor, materials, machine time and other resource elements that go into the manufacture of the product can be estimated by extrapolating backward from the delivery date for the assembled product. If the scheduling is done accurately, there is no need to maintain a parts inventory because of uncertainties in the demand for parts; instead each part can be manufactured just before it is needed.

Suppose a company wants to make 50 pruning shears for shipment on September 1. To determine how many wood handles must be made and when they must be ready the manufacturing-resource-planning system consults a structured bill of materials for pruning shears. It finds that for every pair of shears two wood handles are needed. The system then determines that it takes, say, a week to assemble 50 pruning shears and two weeks to make 100 handles out of wood stock. The wood supplier requires a week's notice for delivery, and so the system automatically generates an order for the wood on August 4, four weeks before the shears are to be ready for shipment. The system might also generate additional orders

DESIGN AND ENGINEERING ANALYSIS can be done with great efficiency on a computer terminal provided with specialized programs. The operator can interact with the terminal by entering data and commands at a keyboard, by employing a "menu" of special-purpose commands or by pointing to the screen of a cathode-ray tube (or to a surface in front of the screen that corresponds point for point with regions of the screen) with a stylus; in addition a few frequently used commands can be issued by means of a hand-held control panel. In the photographs on the opposite page the analysis of the forces on a device called a brace plate is demonstrated. A model of the brace plate is generated (*a*). The plate is then schematically bolted down, an axle is passed through its two collars and a force to be analyzed is applied upward (*b*). To determine the effects of the force on a collar, the axle and one of the collars are enlarged (*c*) and the collar is sectioned by planes (*d*) into a matrix of small regions. The regions are best visualized on the screen if each region is reduced in size by a small amount so that the regions separate. The shrinkage is intended only to improve clarity; it does not affect the analysis. The unloaded configuration of the ring is rotated so that its axis is perpendicular to the screen (*e*). The maximum distortion of the collar under the load is then calculated, and the result is projected so that the distortion along the applied force is 100 times the distortion in other directions (*f*). Images were generated by the Computervision Corporation of Bedford, Mass.



COMPUTER-AIDED-DESIGN TERMINAL enables the designer to create complex shapes by combining simpler ones. In the photograph at the upper left (*a*) a computer terminal displays the basic outline of part of the upper section of a bulkhead for the F-15 fighter aircraft. Three planes perpendicular to the plane of the screen have been defined by three line segments, each of which is marked by an asterisk. The orientation of the plane of the bulkhead is indicated by a triangle with an asterisk; when the triangle is equilateral, as it is here, the bulkhead is parallel to the plane of the screen. In the second photograph (*b*) the lines formed at the intersections of the three planes with the plane of the bulkhead are shown. In the third photograph (*c*) the computer has drawn a curve slightly offset from a curve already drawn. In the photograph at the lower right (*d*) the closed region defined by the curve and by the three lines is automatically given rounded corners. The dimensions of the region, although they are not shown on the screen, are stored by the computer for retrieval when needed for engineering analysis or process design. The images were generated by the McDonnell Douglas Corporation in St. Louis.

for wood to be kept in inventory, but the inventory would be maintained only at the level needed to cover uncertainties in the supply of wood; no reserve would be needed for uncertainties in demand.

In order to introduce manufacturing resource planning successfully a company must have accurate information on the parts needed for each stage in the assembly of a product, on the time needed for manufacturing each part (including not only the time spent actually working on the part but also the time needed for setting up machines, for moving the part from one operation to the next and for delays while the part awaits processing at each station), on the lead time needed for purchasing parts from suppliers and on the company's own inventory. Many companies have failed in their first attempt to set up a manufacturing-resource-planning system because of insufficient data on these elements.

Nevertheless, more than 100 systems for manufacturing resource planning have been developed, and they have been put into use at more than 10,000 manufacturing sites. Their effectiveness has been demonstrated most clearly in factories where a considerable variety of products are made in comparatively small quantities; in these circumstances maintaining a large inventory would cut deeply into profit. Inventory reductions of up to a third and reductions of up to 6 percent in the cost of purchased parts have been achieved.

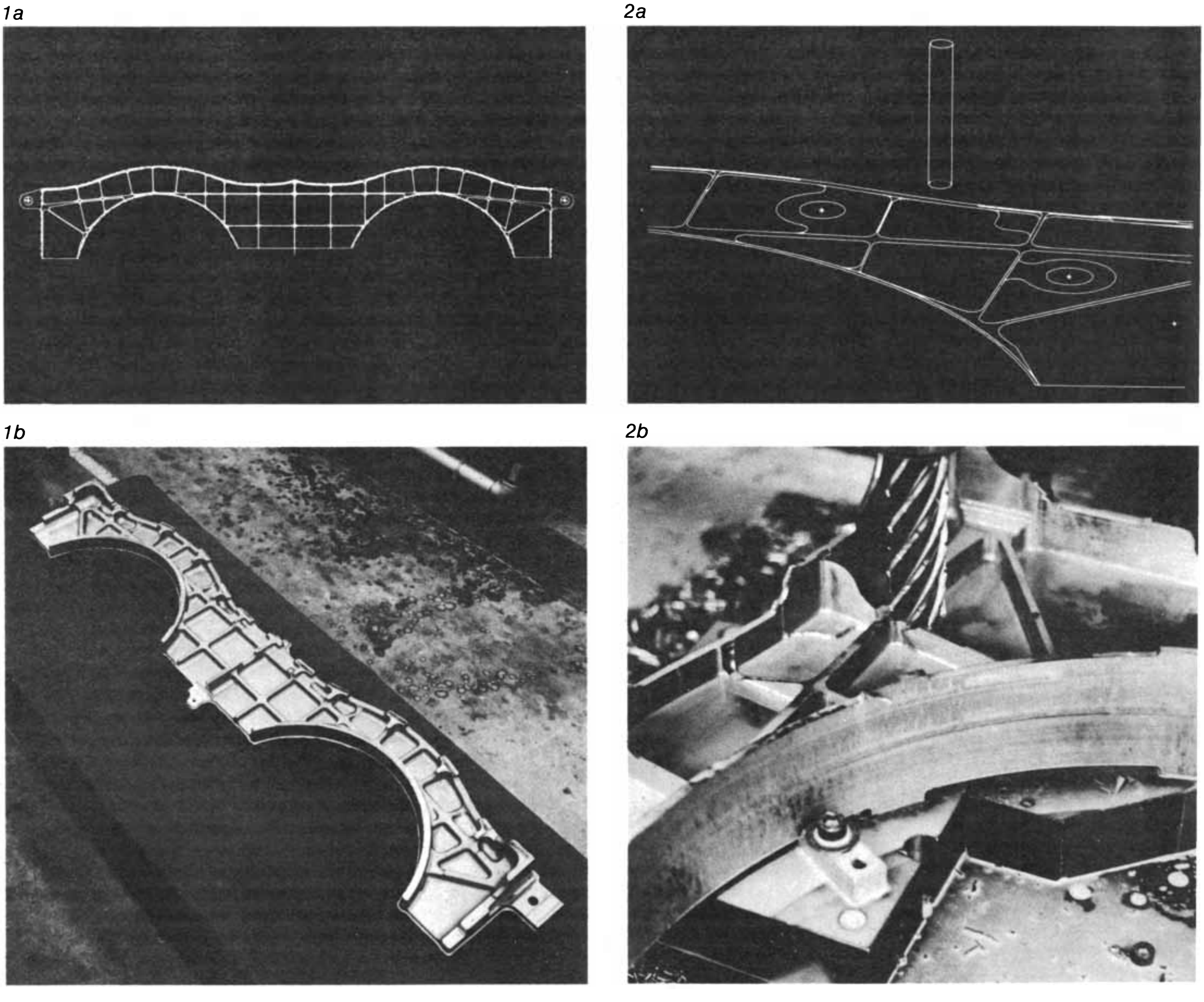
Manufacturing resource planning works quite well in job shops, where many parts are manufactured in varying quantities. When manufacturing is more repetitive, however, a system developed by the Toyota Motor Co. Ltd. called the Kanban system may be even more effective. In the Kanban system the order for a part to be made at one station of a production line is generated only by the requirements of the next station on the line. A chain of orders from work station to work station is thereby set in motion by a single order for finished products at the end of the line. Every component of the finished product, such as an automobile, is pulled through the line by the chain of work orders exactly when it is needed. Thus unlike the manufacturing-resource-planning system, which depends on detailed, centralized planning of all subassemblies, components and raw materials and on efficient feedback from every work station, the Kanban system depends only on the centralized planning of the output of finished products. Moreover, in Kanban the parts are made in the exact quantities needed for production, with no allowances for wastage or spoilage, a feature of the system that requires standards of quality control now met primarily in Japanese factories. In the future computer programs will probably incorporate the

best features of manufacturing resource planning for job-shop production and of the Kanban system (to the extent that non-Japanese societies can incorporate its methods) for repetitive production.

The basic principles of manufacturing resource planning can be extended in a number of ways. The generation of timely part orders can be based on the date the finished product must reach a certain warehouse or distribution center instead of on the shipment date. This method of scheduling is called distribution resource planning, and it must take into account the time needed for shipment. It can be employed to generate shipment dates for various products; its output can become input for a manufacturing-resource-planning system.

The computer can readily bring together information from a manufacturing-planning or a distribution-planning system to generate summary reports for the management of a company. The reports could include the overall backlog of orders, the inventory level, the daily production rate and the daily difference between the input to the plant and its output. If the management wants to consider alternative production rates, inventory levels and the like, the computer can rapidly simulate the consequences of the changes for the rest of the company. Once a production plan is chosen it can still be optimized by the more rigorous mathematical techniques of linear programming and queuing theory.

A common requirement for all versions of resource planning is feedback about operations on the shop floor. Information on the movement of material, the performance of workers and machines and the attendance of workers can be collected by various means. For example, a worker's time card can be imprinted with a machine-readable code such as the Universal Product Code bars, so that the working hours recorded by the time clock are automatically assigned to the worker. The papers that accompany a job through various stages of processing can be similarly encoded, or the product itself can be. Typed messages can be entered from computer terminals throughout the factory. The information enables managers to determine whether a part is meeting the schedule set for it by the planning system, and if it is not, to decide what measures should be taken. The information feedback need not be registered in the computer immediately; in most cir-



STEPS IN THE PRECISION MILLING of the upper half of an F-15 aircraft bulkhead are shown as the process is simulated on the screen of a computer terminal (*upper photographs*) and as it appears on the factory floor (*lower photographs*). The shape and dimensions of the final part, which are entered into the computer by the designer (*1a*), serve as input data for a computer programmer, who then specifies the path of a cutting tool on a rough forging (*1b*). The cutting tool is moved into place above the forging (*2a, 2b*) and enters the

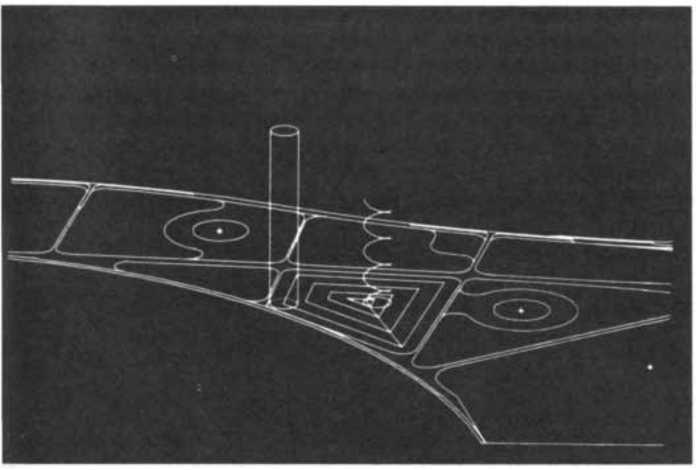
cumstances an update once or twice a day is sufficient.

One of the most important benefits of a system for manufacturing resource planning and control is that it enables the company to respond quickly to changing market conditions. Before the introduction of automatic planning systems the response to changing priorities was the duty of the expediter, and the role of expediter usually fell to the shop foreman. Consequently when such systems are installed, the foreman can go back to being a foreman, that is, he can focus on being the leader of a group of workers rather than spending his time in efforts to relieve shortages of parts, to order repairs for machines and to shepherd the latest top-priority item through the production line.

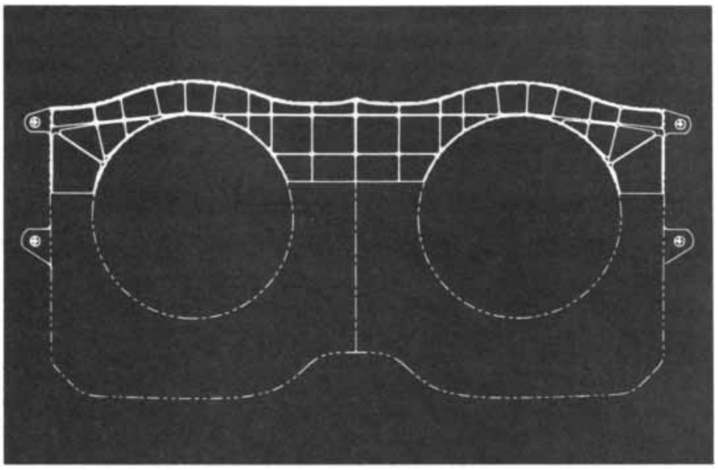
Although I have emphasized changes in the organization of the manufacturing enterprise, the mechanization of operations on the factory floor is also continuing. Data-processing technology can be applied to the control of three general kinds of machines in the factory: machines that store, retrieve or transport materials, machines that process the materials and robots.

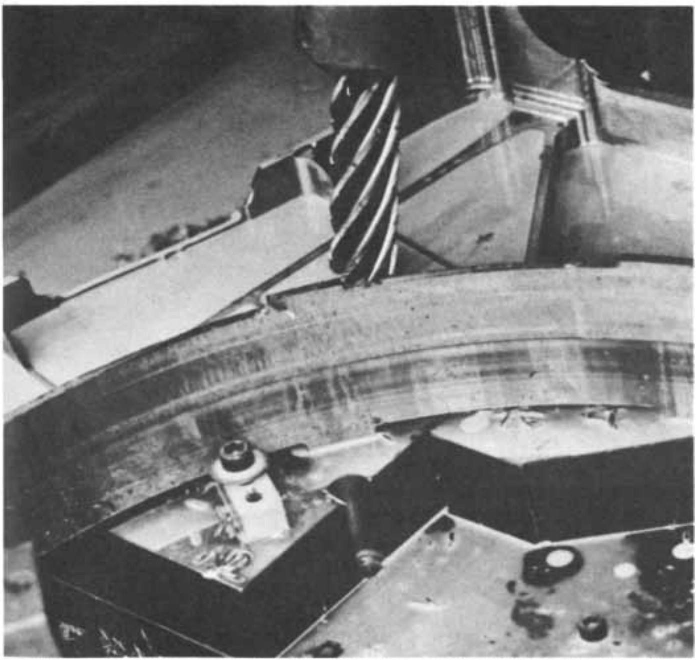
Automatic storage and retrieval systems transfer pallets of material into or out of storage racks up to 100 feet high. Smaller systems called miniloaders hold drawers of small parts. In both cases a part can be selected by number or by location, and an automatic shuttle is actuated that retrieves the part. Essentially such a system is an automatic warehouse in which the shuttle takes the place of the fork-lift truck and its human operator. Similarly, automatic guided-vehicle systems replace conveyors and hand trucks for transporting materials to and from the warehouse and throughout the factory. The driverless shuttle cars can be guided by signals sent through a wire embedded in the floor.

The earliest numerically controlled machine tools were programmed by means of a punched paper tape. Each instruction to the machine was represented by a pattern of holes in the tape; the pattern was decoded by an optical or mechanical reader attached to the tool. In most cases the paper-tape reader has been replaced by a small digital computer mounted on the machine. A modern computer–numerically controlled tool can be as big as a small house and can incorporate a cutting head capable of independent motion around several

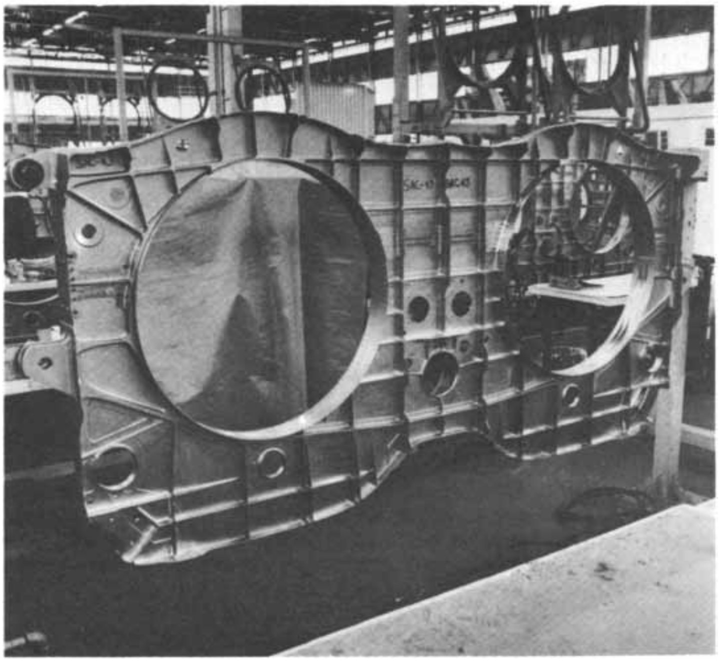


4a





4b



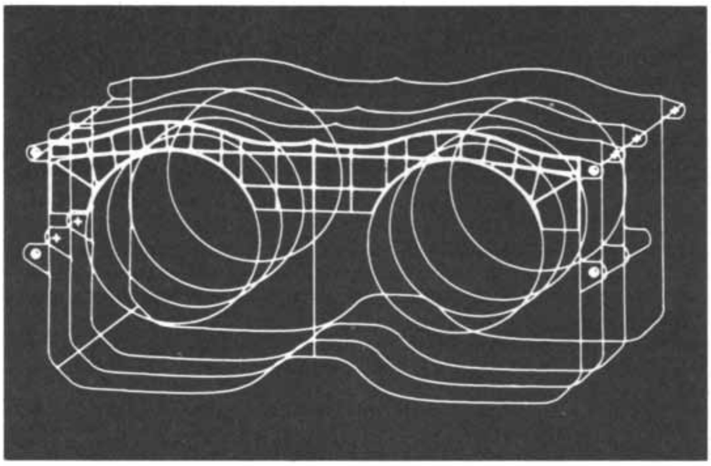
workpiece along a spiral path; it then cuts an ever widening region in the forging (*3a, 3b*). The operation of the milling machine is controlled by the computer program. There are three cutting heads mounted in parallel, so that three bulkheads can be machined at one time. Each cutting head of the machine can move along three axes in space and can tilt around the two horizontal axes, cutting to a tolerance of a ten-thousandth of an inch. The workpiece is attached to a similar machined part to create the finished bulkhead (*4a, 4b*).

axes at the same time; the computer control enables the machine to cut metal automatically to tolerances of a ten-thousandth of an inch. Moreover, the program can prevent the machine from cutting too deep into the workpiece and so ruining the part, and in some cases it can signal the machine operator to change or sharpen the cutting tool when sensors indicate that the torque required to make the cut is outside the proper range of values.

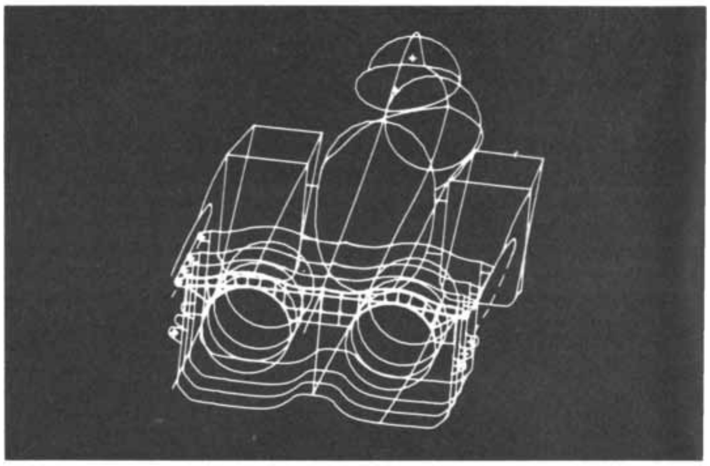
When several computer-numerically controlled machine tools are linked by a hierarchy of computers, they are called direct-numerically controlled machine tools. Typically each machine is controlled by a microcomputer; several machines are linked by a minicomputer, and several minicomputers are tied in turn to a large mainframe computer. The programs for the manufacture of every part the company makes can be stored in a central data base, and they can be transferred from the mainframe computer to any of the machine tools in the network. In addition information about the status of each machine, the volume of its production and the quality of the finished parts can flow back to the mainframe computer from the peripheral controllers. As many as 100 machine tools can be connected in such a hierarchy.

In a direct-numerically controlled system the only connection between the tools is electronic; the workpiece must still be moved from one machine to another by manual methods. If several direct-numerically controlled machine tools are further linked by a materials-handling system and the mainframe computer is programmed to operate the tools in a specified sequence, the result is called a flexible manufacturing system. In such a system families of parts are selected through group technology for machining. Once a pallet of workpieces is set in place the workpieces proceed automatically from tool to tool, where they are machined in the proper sequence. The entire system may require loading and unloading only once a day; one person is needed to oversee the operation of the system for the rest of the day. Furthermore, the fraction of each shift a machine spends cutting metal can be as high as 50 to 90 percent in a flexible manufacturing system; with a computer-numerically controlled machine tool standing alone the cutting time may be as low as 10 to 30 percent of the total shift time.

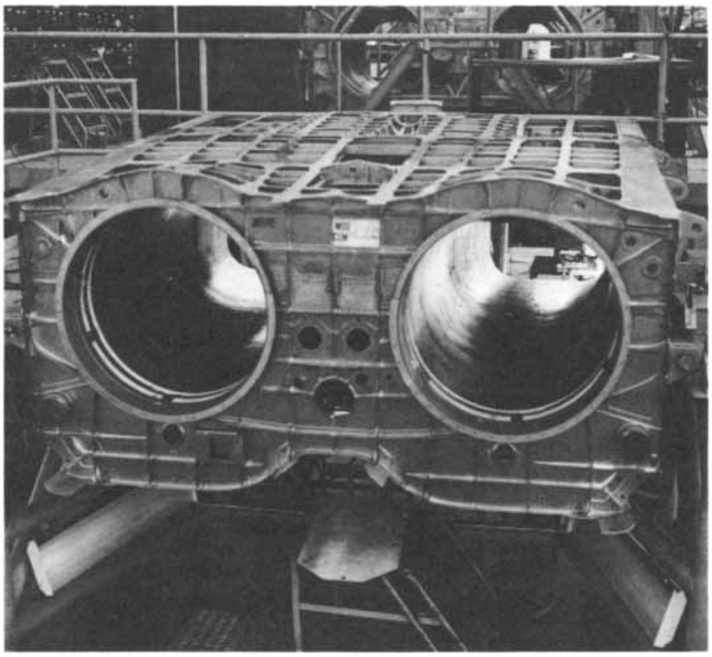
5a



6a



5b



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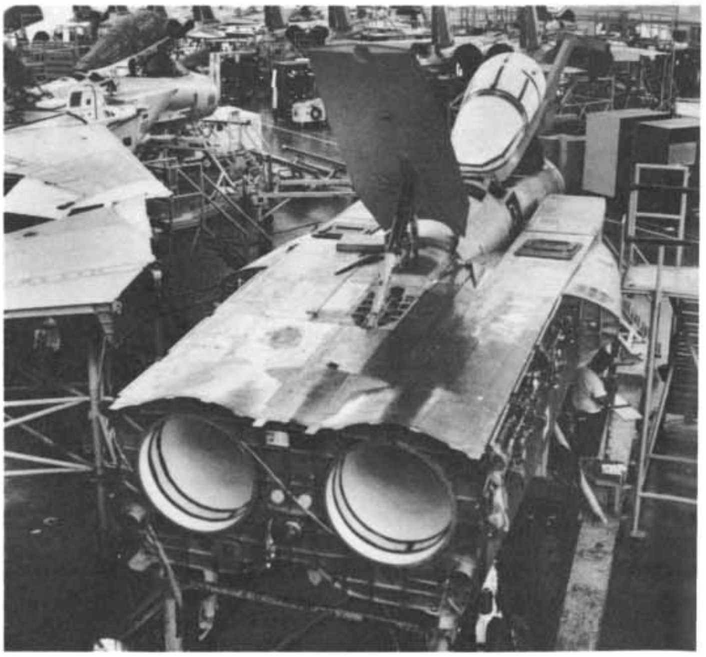


ASSEMBLY OF THE F-15 AIRFRAME is not yet automated, but its stages can nonetheless be planned at the screen of a computer terminal. In the upper photographs successive stages in the assembly are shown as they appear on the screen; in the lower photographs the corresponding stages are shown in the assembly plant. The bulkhead is first mated to three similar bulkheads to form the midsection of the aircraft (*5a, 5b*), the midsection is attached to the front section (*6a, 6b*) and finally the wings and tail section of the aircraft

The higher the level of integration among machines, the greater the need for some form of automatic inspection of products. A worker operating a machine tool manually can note a defect and stop work immediately, but a machine running autonomously could, through a mechanical failure or a programming error, ruin an entire batch of parts. Information from various sensory devices on the machines can be employed to accept or reject individual parts. The information can also serve to build a statistical data base. The statistical summary is required in certain industries, such as pharmaceuticals and aircraft manufacturing, and statistical feedback makes it possible for the computer that controls each machine tool to adjust the tool during production.

A manufacturing system that has become emblematic of factory work in general is the assembly line. It should be noted that the assembly line is not necessarily a mechanized system; it is a method of organizing work that can be applied either to human workers or to machines. Many products are still assembled by hand, with each worker doing one small step of the job and passing the workpiece on to the next station.

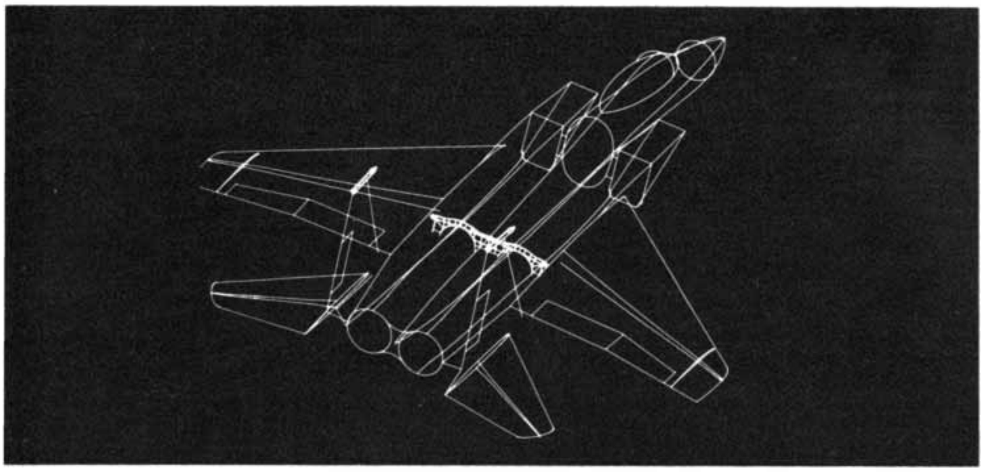
For products that are made in large quantities the assembly process can be automated entirely by building a single-purpose machine. The design and construction of such machines constitute a highly developed art that draws on a variety of ingenious methods for orienting parts, fitting them together and fastening them. In most instances the design of the product itself is modified to facilitate automatic assembly. The chief disadvantage of such "fixed tooling" is a lack of versatility: a machine for the assembly of fountain pens cannot be adapted to the manufacture of ballpoint pens when the demands of the marketplace change.

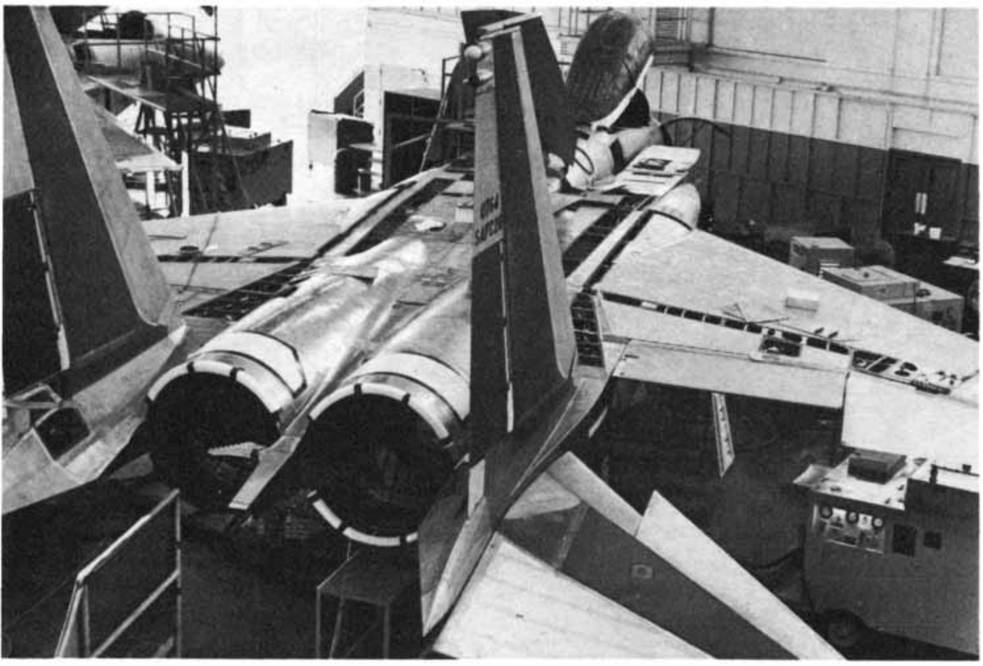
The robot, a programmable machine capable of moving materials and performing repetitive tasks, is beginning to make automated assembly economically feasible in some lower-volume applications. In certain cases the robot replaces a human worker carrying out some routine operation, such as loading products onto a pallet. In other cases a system of robots is a more flexible (but generally slower) alternative to fixed tooling.

The main difficulty in the use of robots for assembly is that the robot is not yet able to pick a randomly oriented part out of a bin. If the orientation of the part is preserved at all stages of the assembly process, however, the robot can compete economically with other machines. One of the most important applications of robots in the U.S. is in the loading and unloading of machine tools. The other primary applications so far are in jobs that are dirty, hazardous, unpleasant or monotonous. Between 5,000 and 7,000 robots are currently used in American industry for spot welding, spray painting, machine loading and unloading and certain assembly operations. In Japan the robot population is about 80,000, but the Japan Industrial Robot Association accepts a broader definition of robots, including simple mechanical manipulators with mechanical stops that would not be considered robots in the U.S.

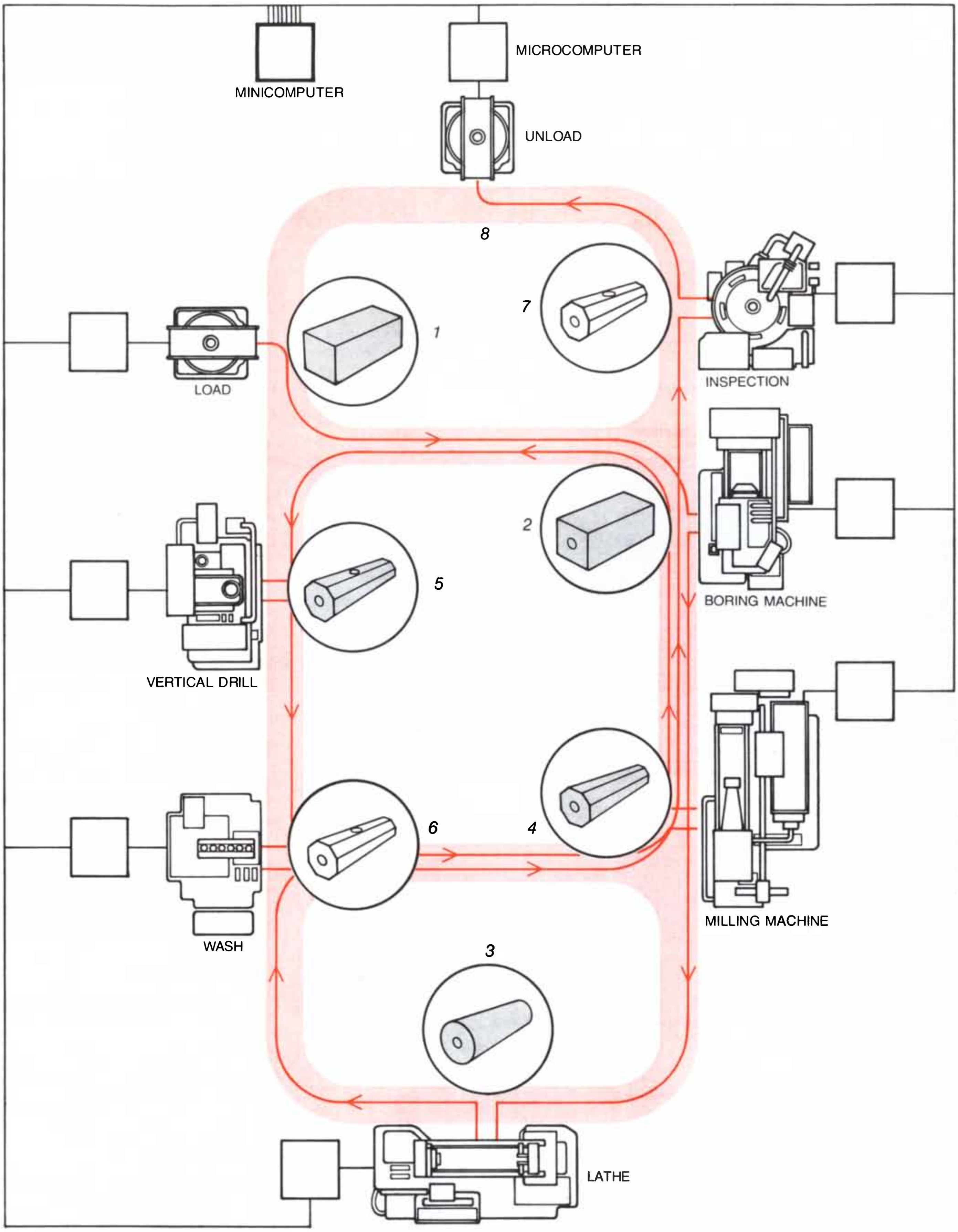
Although robots and computer-numerically controlled machine tools are alike in being programmable, the robot is generally much smaller and can easily be moved about. Moreover, in many cases the robot is programmed analogically, that is, by placing the device in the "teach" mode and moving its arm exactly as the job demands. Hence many robots act as recording and playback devices that simulate human motions, although they can also be programmed with a set of coded instructions in a high-level computing language. Their main advantage over human workers is that their performance never varies; they are rarely faster than human workers, but they never tire and they are often more reliable.

The integration of the six major areas of manufacturing technology—design, group technology, manufacturing resource planning and control, materials handling, manufacturing process machines and robots—depends on a carefully designed hierarchy of information flow. The linkage of the six areas is brought about by a centralized proc-





are added (*7a, 7b*). The turbine engines are installed during a later stage in the assembly. One advantage of the computer simulation of the assembly is that the designer can determine at a glance whether or not the components will fit together properly. The photographs on these two pages and on the preceding two pages were made at McDonnell Douglas in St. Louis.



FLEXIBLE MANUFACTURING SYSTEM is an automated set of programmable machine tools for metalworking. The machines are controlled by a hierarchy of computers and are linked by a conveyor that carries workpieces from one machine to the next. The minicomputer determines the overall sequence of operations to be carried out on each workpiece. When the workpiece reaches a machine, the minicomputer also directs the machine to select a cutting tool and "downloads" a program into a smaller microcomputer that controls the cutting path of the tool. Flexible manufacturing systems have now been built that can run for hours without intervention. Parts to be machined are loaded at the entry to the system during the first shift, and the system operates throughout the second and third shifts. Setup times are so reduced that such a system may be able to manufacture 100 randomly selected rotational parts in 72 hours.

essing system, but there are also many kinds of information in each of the areas that need not be centrally stored. Distributed, or decentralized, data processing has become possible in the past 10 or 15 years because of the tremendous growth in microelectronic components and the decreasing cost of storing and manipulating information. In manufacturing, as in other sectors of the economy, the trend is to disperse powerful minicomputers and microcomputers to the individual workers, making each worker responsible for data entry and processing control. Computers can then be linked to one another and to the central data base of the company by telephone lines or another telecommunications network.

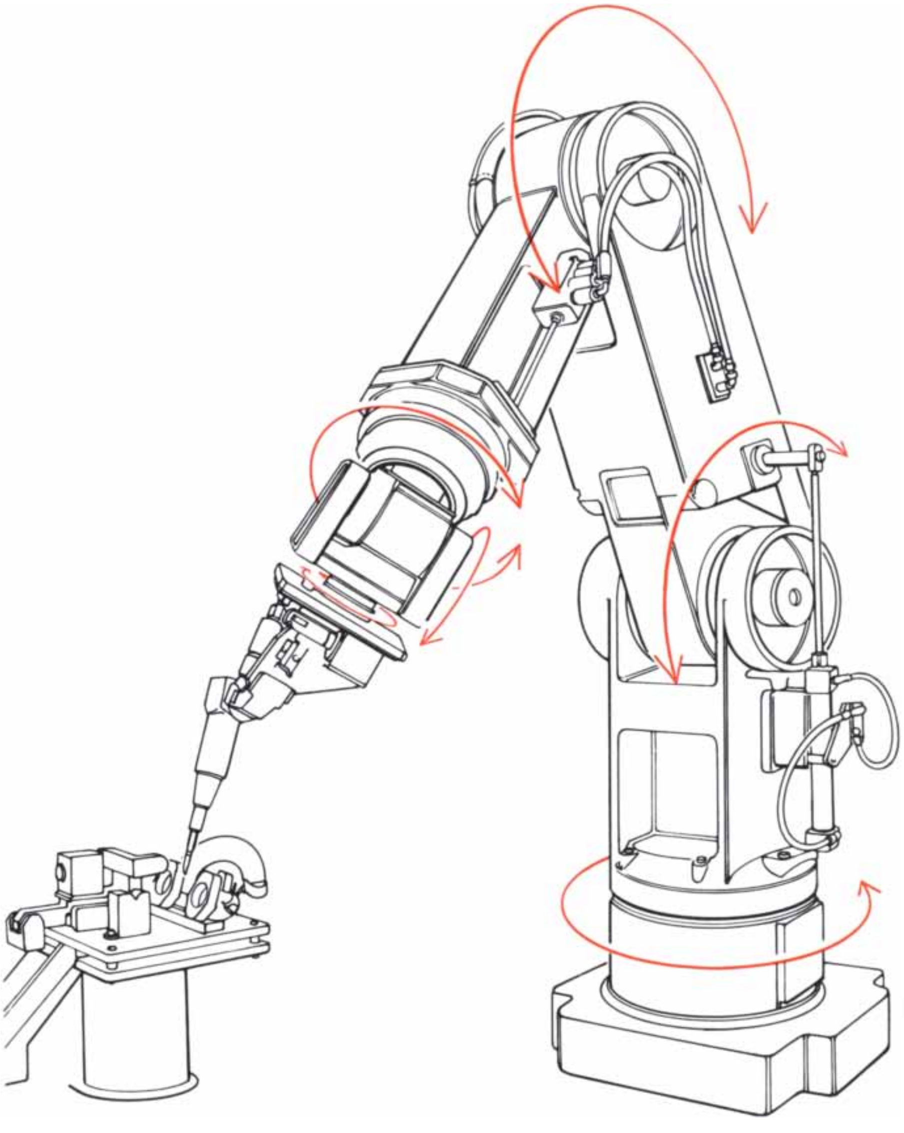
Given the capabilities of existing technology, it is possible to imagine in some detail how a factory could operate if all six of the areas I have discussed were linked in interdependent modules. The factory floor would be divided into cells defined by their manufacturing function, such as a design cell, a flexible-machining cell, a welding cell and an assembly cell. Dozens of robots might be linked by a hierarchy of computers, much as direct–numerically controlled machine tools are today. Feedback to the manufacturing control systems from the robots, from the machines and from the people in the factory would be immediate, and so the planned flow of products through the factory could be adjusted continuously to reflect changes in operating conditions. The design of the plant would emphasize flexibility, so that a variety of products could be made by the same machines; indeed, products might be made in unit quantity.

Communications between the factory and a company's most important outside customers, suppliers and subcontractors would be carried on directly among the computers of the various organizations. Drawings, for example, would not be issued to a subcontractor; instead the geometric data and machine-tool programs needed to shape a part would be transferred electronically to the subcontractor's computer. Similarly orders from major customers or to major suppliers would be transmitted electronically. Within the company separate divisions would be interconnected by a satellite-based communications system.

The size of the individual manufacturing plants is likely to be small: fewer than 500 people per plant in most cases. For the manufacture of some types of products the size of a plant could be as small as five workers. The Yamazaki Machinery Corporation of Florence, Ky., is setting up a plant for the manufacture of machine-tool parts that will employ only five workers on the first shift, one worker on the second shift and one on the third. Such small plants would create a more personal working environment, and the efforts at each plant would be focused on the manufacture of a few families of products. No single plant, however, would have much influence on the policies or financial well-being of the company as a whole.

The reduction in the number of blue-collar workers in factories is likely to continue as robots and flexible manufacturing systems are installed. Many other trends in manufacturing, however, will affect skilled professional workers as well as craftsmen and laborers. Mid-level white-collar workers will probably have to be retrained to exploit the new technology, and engineers will find it necessary to continue their education. Hence it is likely that corporate design centers will continue to be attracted to the environs of cities with major educational centers, such as Boston and San Francisco. Independent engineering service companies will probably establish themselves near the same cities.

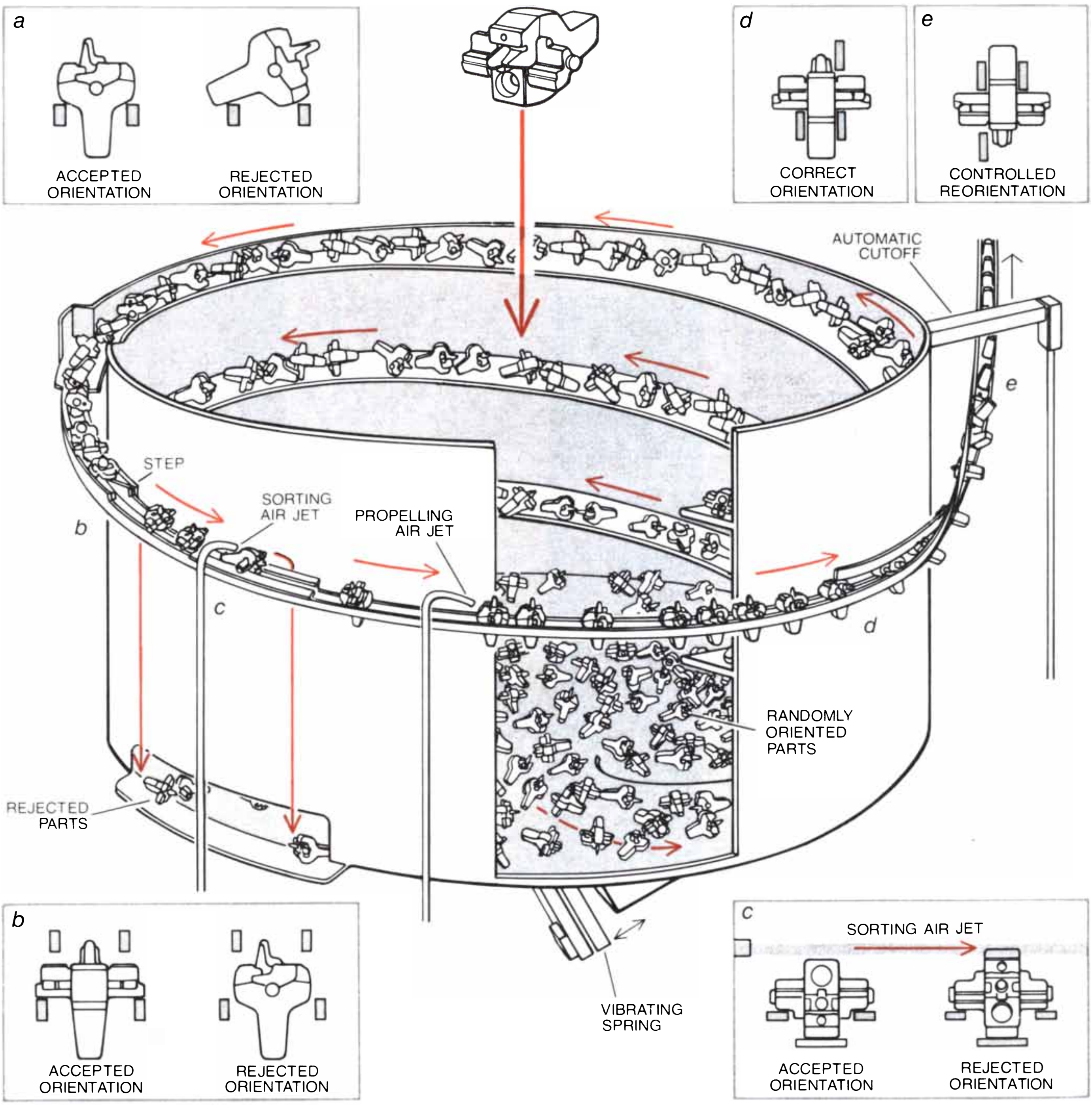
Given the undeniable dislocations in the work force and the expense of information-processing technology, why would one expect the technology ever to be installed? For the short term the answer most often given is that manufacturers must compete in worldwide



ROBOT ARM capable of independent movement around six axes is a freestanding machine that is programmed analogically. An operator "teaches" the robot a three-dimensional pattern of motions by moving the end of the arm through a sequence of positions and orientations. The robot records the maneuvers in the memory of a computer and repeats them indefinitely when it is called on to do so. The end of the arm can be fitted with a grasping device or another tool, such as a paint sprayer or a pair of spot-welding electrodes. The robot is shown with a spinning abrasive tool for deburring castings. The robot has no sensors, but several other kinds of robot have been equipped with devices that sense torque, gripping force, the visual field and other features of the environment. It has not yet been possible, however, to endow a robot with the ability to pick a randomly oriented part out of a bin of similar parts. Hence, unless the orientation of a part is constrained before the robot encounters the part, the adaptability of the robot to assembly and other tasks that require the exact orientation of the part is limited. The illustration shows the Type 80 vertical robot manufactured by the Ateliers de Constructions Mécaniques et Automation (ACMA) of Beauchamp, France, a subsidiary of Renault.

markets. Manufacturers who acknowledge that information technology will put people out of work argue that without the technology they would not be able to compete at all, and all of their employees would lose their jobs.

The mechanization of design and manufacturing promises the manufacturer higher productivity, better quality at lower cost, the ability to give better customer service and the flexibility to meet the demand for an increasing array of products and options that have shorter life cycles than ever before. In sum, information-processing technology will continue to revolutionize the way work is done in design and manufacturing. Information and the ability to transmit it quickly will come to be recognized as a resource as valuable as money in the bank or parts on the shelf.



CORRECT ORIENTATION OF PARTS is a prerequisite of automatic assembly, but it is one of the most difficult processes to mechanize. For small, lightweight parts a device called a vibratory feeder can do what a robot cannot: it can reject all configurations of the part except the one needed for automatic assembly. In the illustration a bin of randomly oriented toggle switches is mounted on a system of springs and vibrated up and down at a rate of between 60 and 120 times per second. The vibrations impart a twist or torque to the bin, with the result that the switches "walk" up a spiral ramp on the inside of the bin. At the top of the bin the ramp meets a two-rail track, and the switches either fall off the track and back into the bin or continue to move along the track with the toggle pointing down between the rails. Only one of the four possible orientations can be accepted, and so the switches are sorted at two stations along the track. At one station they move down a series of steps in the track and the vibrations cause switches in two of the four orientations to fall back into the bin. At the second station the rest of the wrongly oriented switches are blown back into the bin by a jet of air. The device can feed correctly oriented toggle switches to the assembly machines at a rate of 2,400 per hour. Vibratory feeders can be constructed for orienting almost any small part, but for parts longer than about six feet or heavier than about half a pound the rapid wear of the vibrating parts makes such a finely tuned system impractical. The machine in the diagram is manufactured by the Bodine Corporation of Bridgeport, Conn.

The Mechanization of Commerce

Such services as finance, transport, distribution and communications are being mechanized even more than the production of goods. In the process they call for workers with ever higher levels of education

by Martin L. Ernst

Commerce encompasses all the economic interactions among the members of a society. It is information-intensive: it requires that information be made available on goods, their prices and their utility, and the modern means of paying for goods requires that financial information be transmitted between the parties involved. Moreover, the storage and transportation of goods call for detailed records such as schedules and manifests. Commerce has therefore been quick to adopt new forms of technology for processing information. Clay tablets found in the Middle East furnish strong evidence that writing originated with commercial records. More recently the sales history of computers shows that the large-scale industrial application of computers began with commercial functions.

Today, when commerce is responsible for more than 35 percent of all employment in the U.S., the new electronic technologies dominate the mechanization of financial institutions. In other commercial sectors nonelectronic machines play a larger role. Beyond this some central themes emerge that are useful for understanding the mechanization of commerce: how it arises, how it is implemented and what its impacts are likely to be. Here I shall give a series of examples to develop these themes. The examples will come from four major areas: finance, transportation, the distribution of goods and lastly communications.

One theme concerns the role of government in commerce. Traditionally governments have performed certain commercial functions or have intervened in them. Good coinage, honest weights and balances, well-maintained roads and port facilities and equitable (or at least consistent) judicial systems played a major part in establishing the success of city-states and later of nations. Hence most aspects of finance, transportation and communications in the U.S. have been subject to considerable regulation, and the first-class mail service is operated by the Government as a monopoly. In many countries the same activities are conducted almost entirely by government organizations, and in virtually all countries a major part of the legal structure is devoted to codes concerned with commercial transactions. Inevitably, then, government intervention has influenced the adoption of new technology in commerce, sometimes favorably, sometimes not. The basis on which an industry is subsidized or regulated establishes incentives that favor the rapid adoption of some technical applications and the slow adoption of others.

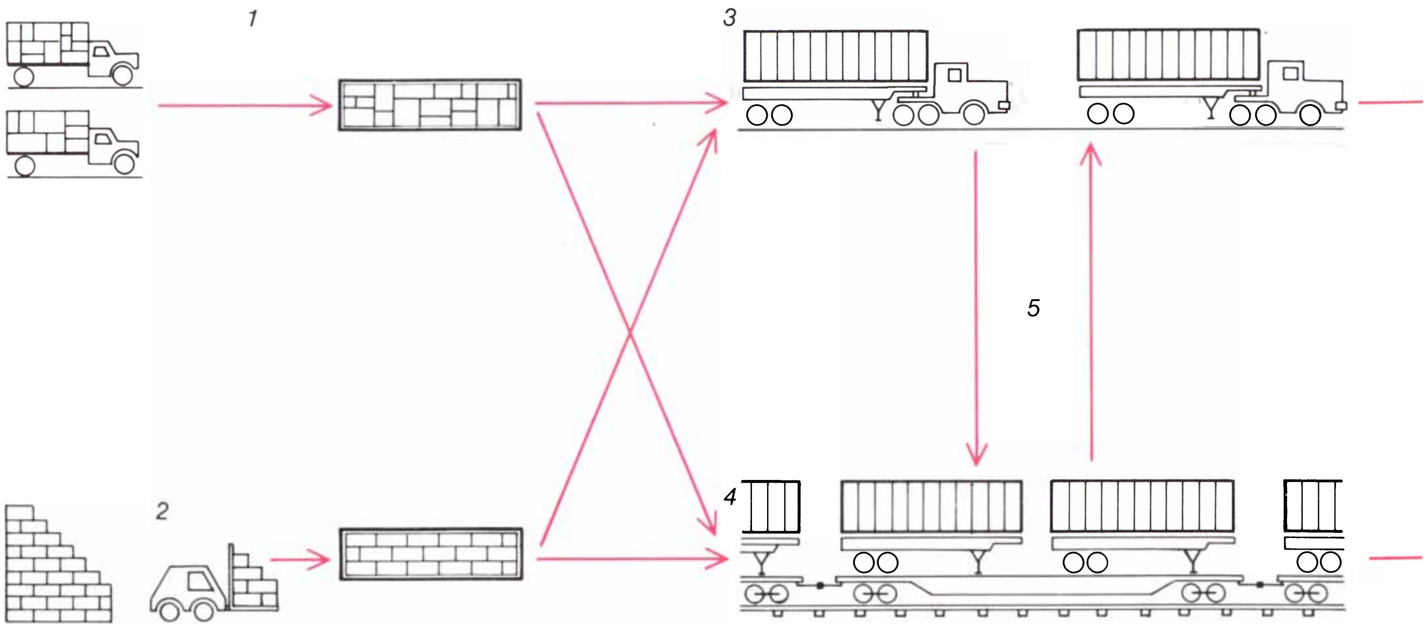
A second theme is the almost universal requirement in commerce for interactions among independent parties. Banks must cooperate with one another, and moreover they must have a considerable degree of uniformity in their basic procedures if checks are to be a useful way to pay bills. Transportation companies, wholesalers and warehouse operators must work together to ensure the flow of goods from factories to stores. Even the U.S. Postal Service and the Bell System, which hold a dominant position in their field of communications, must rely on others for significant parts of their total function. For example, the Postal Service relies on airlines and on the manufacturers of sorting machines. The need for cooperation often limits individual organizations in their choice among available technologies. Often a move toward mechanization can be made only after broad agreement within an industry or across several industries, and this requirement can dictate the pace and the nature of change.

In the light of this second theme the third is ironic. Many of the most effective mechanizations in commerce have been based on quite modest devices. Many others have been based on new configurations of standard machines. Often they are machines that have long been used in other economic sectors.

Among financial industries banking offers the widest scope for examining the nature and impact of mechanization. A good place to begin is with a familiar item: the checks people and businesses employ to receive and make payments. Offered by some 14,000 commercial banks (and now by some 5,000 savings banks through Negotiable Orders of Withdrawal, which are the equivalent of checks), checks and their processing have always been labor-intensive and form an obvious target for mechanization.

Regardless of where it is deposited, a check, or at least the information on it, must be returned to the person who wrote the check by way of his bank. The journey is sometimes a long one. The mechanization of the process began years ago with the introduction of electromechanical check-sorting equipment and bookkeeping machines. Then the Federal Government began producing almost all its checks on punch-card stock. These early steps, however, were fairly limited. The start of modern check processing was the introduction of magnetic-ink character recognition (MICR) encoding on all checks. These machine-readable numbers identify the account on which the check is drawn and the bank in which the account is held. Complete machine processing becomes possible when numbers that identify the receiving account and the bank are entered into computerized records by the bank at which the check is first

CONTAINERIZED SHIPPING exemplifies the application of an ancient and fundamentally simple technology, containers, to the mechanization of modern commerce. Here containers are arrayed on the dock of the Global Marine Terminal in Port Elizabeth, N.J. Most of them are 20 feet long and hold from 8.5 to 11 metric tons of goods. The ship is the *Neptune Diamond,* out of Singapore, which makes a circuit of five U.S. ports and five ports in the Far East. It carries a maximum of 2,100 20-foot containers, about a fourth of which are off-loaded at the Global Terminal and replaced by other containers during a stopover of some 30 hours.

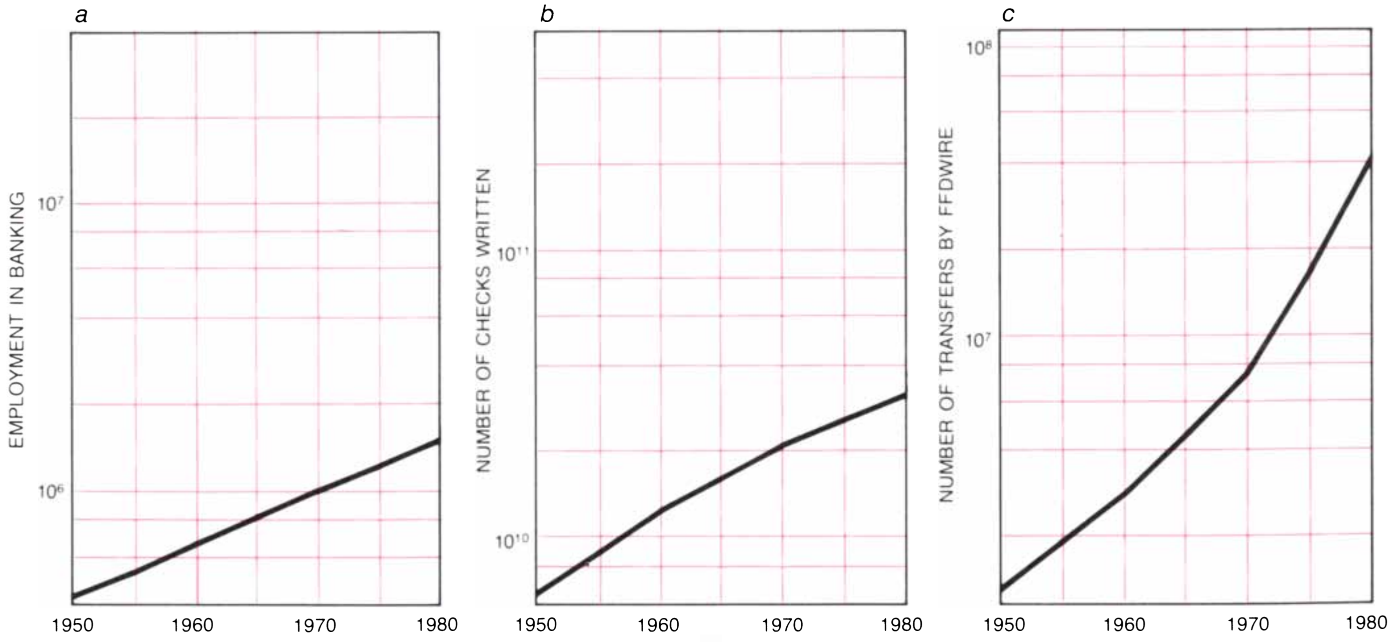


MOVEMENT OF CONTAINERS serving a transoceanic shipping route is diagrammed. Goods from small shippers are packed in containers at local terminals by consolidators and freight forwarders (*1*); goods shipped in large quantity (*2*) need no such mediation. The containers are carried overland by truck (*3*) or train (*4*); the trains may be organized specifically to move sets of containers. In some instances containers are transferred from one mode of transportation to another (*5*), a circumstance favoring the growth of transportation compa-

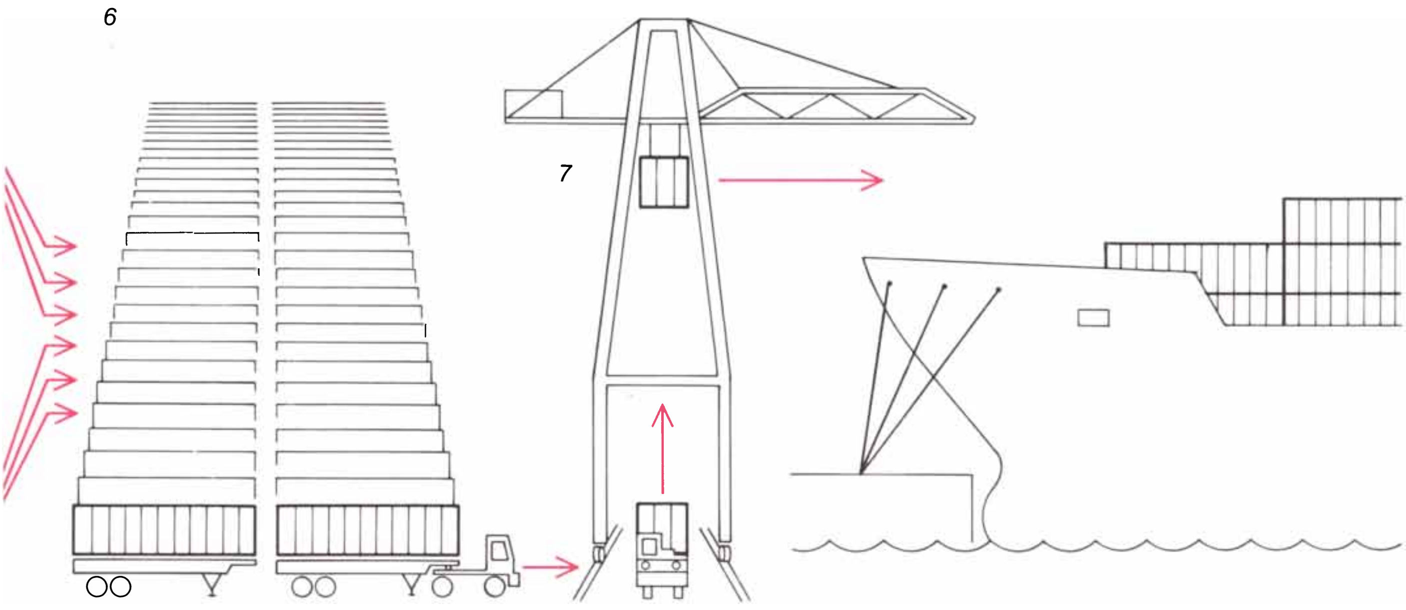
deposited and the amount of the check is MICR-encoded on the check itself.

The introduction of MICR took almost 15 years. It began in the early 1950's with a series of studies sponsored by several bank associations and the Federal Reserve System. In 1958 standards for coding, the position of codes on checks, an acceptable printing ink and similar requirements were established. Another 10 years were to pass before essentially all banks employed MICR, but with the larger banks taking the lead some 85 percent of all checks were being encoded with MICR numbers by 1963. The process illustrates the long time it takes when a large number of organizations must be brought together to make standard changes, even if the changes appear to be simple.

MICR's stream of machine-readable data speeded the development of computer-based record keeping for virtually all checking accounts. And the benefits of having mechanized account records spread rapidly to other bank activities. Computer-based equipment for tellers was introduced early in the 1960's to speed the entry of data and the processing of transactions that originate at a teller window. More recently the existence of computer account records has facilitated the growth of automatic teller machines (ATM's). These have become increasingly popular; cash withdrawals and certain other operations, such as transfers between accounts at a single bank, can now be done at any time rather than only during banking hours.



SIX INDICATORS OF GROWTH in the U.S. banking industry are charted logarithmically, so that equal rates of increase among the indicators would be represented by lines of identical upward slope. Employment in the industry (*a*) more than tripled in 30 years, and its share of the civilian work force more than doubled (to 1.5 percent in 1980). Meanwhile the number of checks being written (*b*) increased almost fivefold, the number of interbank transfers of funds handled by the Federal Reserve System's telecommunication network, Fed-

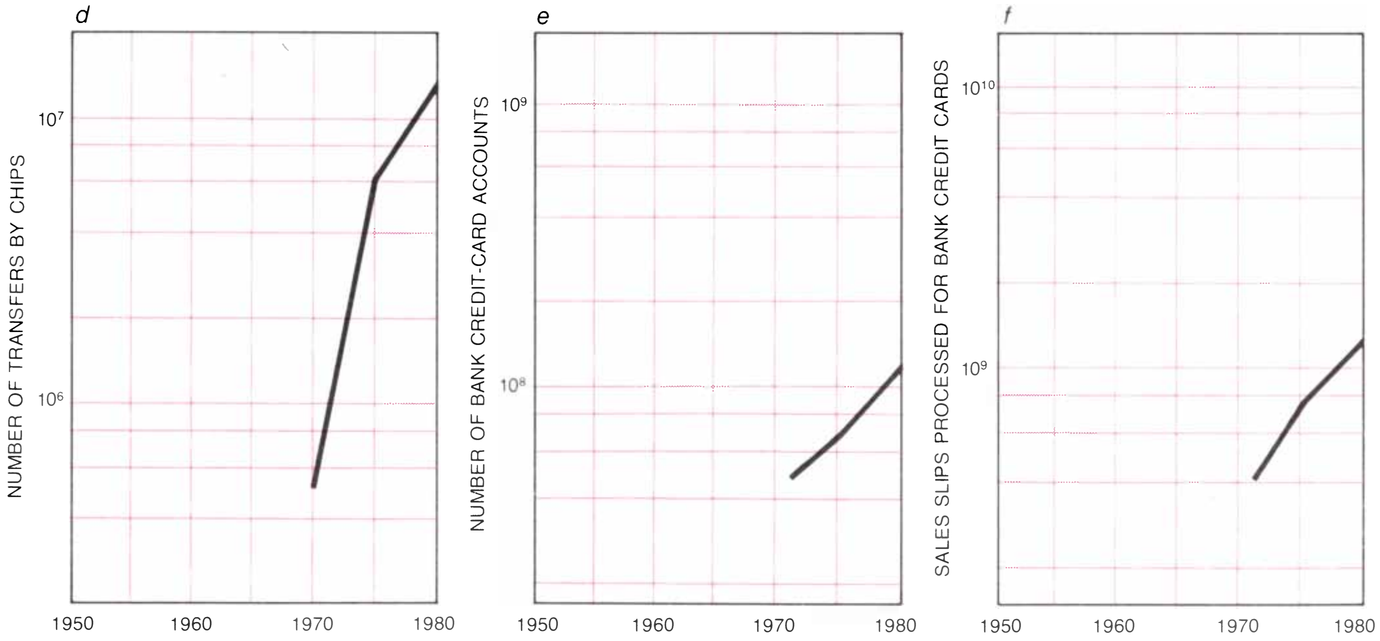


nies that operate in more than one mode. On the dock (*6*) the containers get the attention of longshoremen and customs brokers and agents; then they are taken by a specialized tractor to the crane (*7*) that transfers them to a ship. The wheel flatbeds that carried the containers are left behind. A counterflow, managed by computer, sends empty containers to where they are needed. Computers also keep track of containers' locations and transmit ships' manifests (cargo lists) from port to port ahead of the ships by telecommunications.

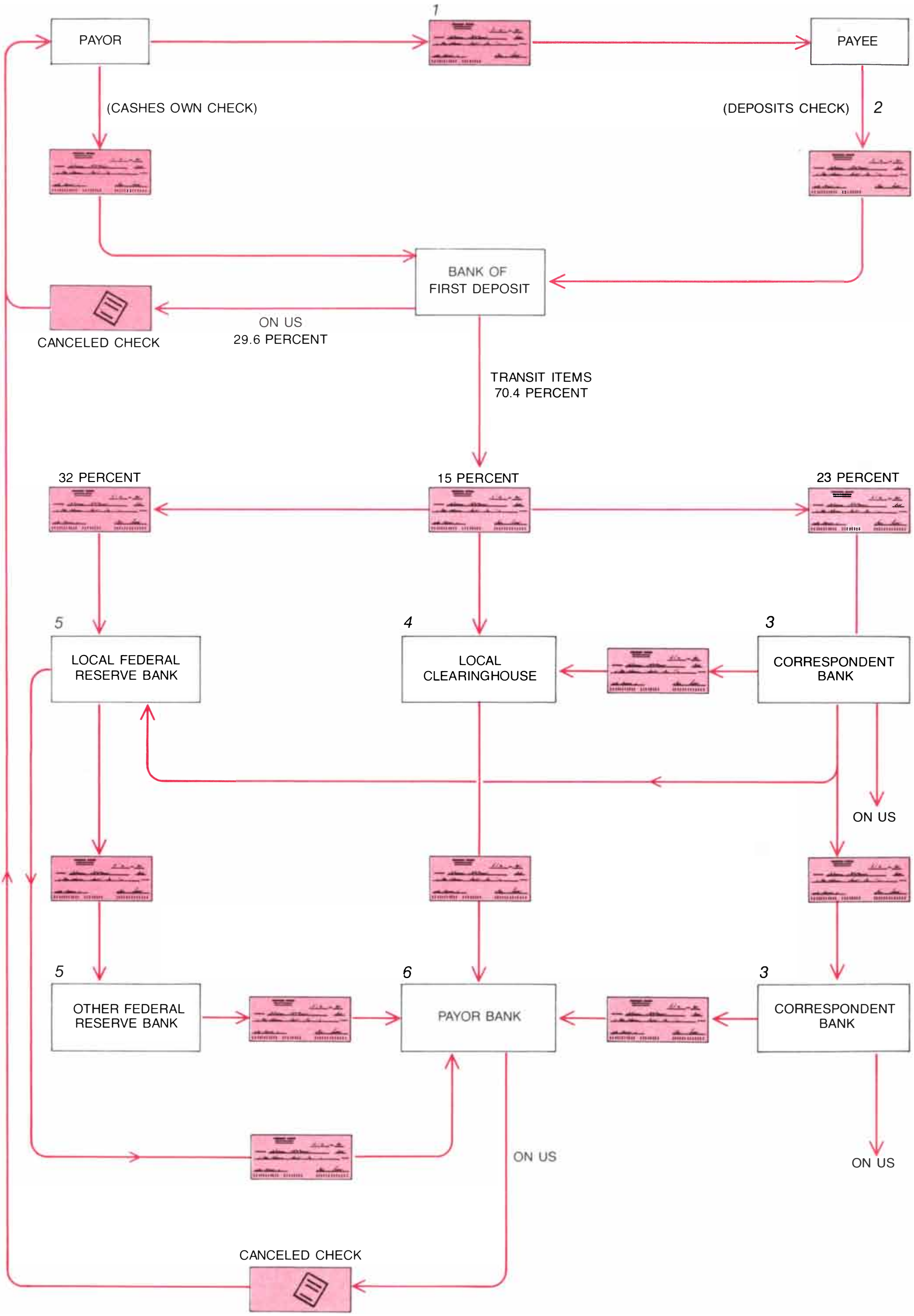
The ATM's illustrate a characteristic of much of the mechanization of commerce. In an ATM transaction the customer himself punches a set of codes into a terminal; thus he provides his bank with machine-readable data. In effect he is doing work for which the bank previously had to use its own staff. This type of "labor sharing" is becoming increasingly common. It is part of a trend that has been under way for decades; in the 1930's, for example, self-service in supermarkets began to replace what used to be the function of store clerks.

A logical next step in the evolution of check processing will be for payments to be made by means of an electronic terminal in the home. The terminals themselves are technically quite straightforward. Their installation nonetheless awaits several developments. First, the population of home terminals must be large enough to make a bill-paying service economically feasible. Second, enough banks and merchants must agree on the terms of the service to give it a reasonable degree of universality. Finally, consumers must have reasons to want to use the terminals.

Potentially there are incentives for all the participants in such systems. Viewed in their totality the costs of checks are not small. When a check is used to pay a bill, for example, the cost is about \$1. Somewhat more than half of that cost is incurred by the banks, and the remainder is incurred by the biller and the payer for postage, paper and printing. The current costs, however, are almost invis-



Wire (*c*), increased more than thirtyfold (the transfers in 1980 had a value of \$78.6 trillion) and private transfer networks such as CHIPS, or Clearing House Interbank Payment System (*d*), began operation. In addition bank-issued credit cards (*e, f*) appeared. Before 1970 the growth of the banking industry reflected the growth of the population and the increasing popularity of checking accounts. Since 1975, however, the growth (supported by mechanization) has reflected the increasing rate at which money flows from one investment to another.

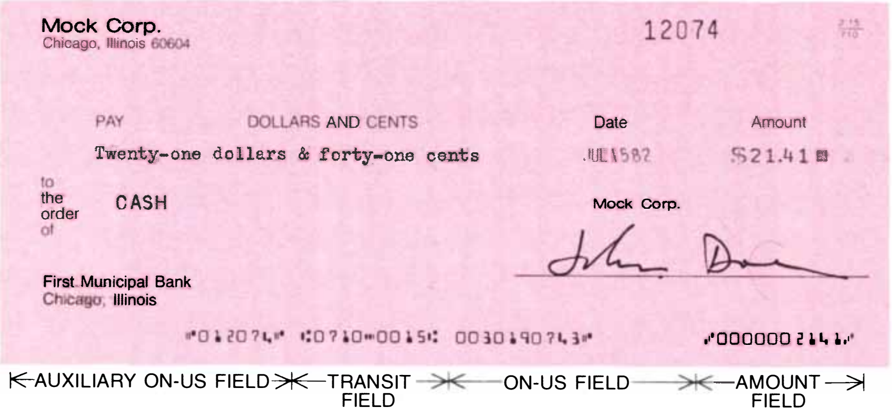

1
PAYOR
PAYEE
(CASHES OWN CHECK)
(DEPOSITS CHECK)
2
BANK OF FIRST DEPOSIT
CANCELED CHECK
ON US
29.6 PERCENT
TRANSIT ITEMS
70.4 PERCENT
32 PERCENT
15 PERCENT
23 PERCENT
5
LOCAL FEDERAL RESERVE BANK
4
LOCAL CLEARINGHOUSE
3
CORRESPONDENT BANK
ON US
5
OTHER FEDERAL RESERVE BANK
6
PAYOR BANK
3
CORRESPONDENT BANK
ON US
ON US
CANCELED CHECK

ible to the consumer: they are "bundled" into the total cost of bank and merchant services. Since most people are comfortable writing checks, many will be reluctant to change unless they get some benefit in the form of lower costs, greater convenience or extra service. In effect people may insist that they be rewarded for the labor they provide when they handle transactions electronically.

Service to individuals is only part of a bank's operations; relations with business organizations are at least as important. In this regard a major factor in mechanization has been the drive by businesses to improve their cash management. As interest rates have risen the number of ways in which a business can earn (or save) interest on short-term loans has grown. To earn or save the interest, however, the business must know its cash position accurately and be able to move its cash around quickly and economically. To meet these needs a variety of electronic terminal systems have evolved that enable businesses and other organizations to communicate directly with bank computers. By means of these terminals a business can keep track of its liquid assets almost minute by minute and can issue instructions for transferring them to where they can be best employed.

In order to move the funds rapidly banks in turn must be interconnected with one another by computer-to-computer telecommunications networks. The oldest and most important network is FedWire. FedWire, which began in 1918 when the Federal Reserve System leased a set of telegraph lines, serves to make settlements of the payments between banks that result from the totality of checks and other transactions individual banks have processed. The settlements are final, in that the interbank payments transacted by way of FedWire are guaranteed by the Federal Reserve System. Other major wire systems are CHIPS (Clearing House Interbank Payment System), which is operated by the New York Clearing House Association; BankWire, which is managed by an open consortium of U.S. banks, and S.W.I.F.T. (Society of Worldwide Interbank Financial Telecommunication), which originated as a European international system but now has many U.S. members. Among these, CHIPS provides the most dramatic example of growth and utilization.

CHIPS was established in 1970. It replaced an earlier system in which paper checks had been carried by messengers from major banks to the New York Clearing House, which provided a facility for settling local interbank accounts among its members. As the traffic in checks grew it became increasingly difficult for clerks in the individual banks to process the day's transactions with any assurance that outgoing payments (for which their bank would be responsible) were adequately covered by deposits and payments flowing in. The danger was either that the local checking system would lose its timeliness or that clerks would be forced to rely on their own judgment to decide whether or not to forward specific outgoing payments. In forwarding some payments the clerks rather than senior bank officers could be authorizing large amounts of credit.


Mock Corp.
Chicago, Illinois 60604

12074

2-15/710

PAY DOLLARS AND CENTS
Twenty-one dollars & forty-one cents

Date JUL1582

Amount $21.41

to the order of CASH

Mock Corp.

First Municipal Bank
Chicago, Illinois

⑈012074⑈ ⑆0710⑉0015⑆ 0030190743⑈ ⑈0000002141⑈

FLOW OF CHECKS back to the payor's bank (the bank on which they are drawn) is facilitated by mechanization that depends in turn on the machine-readable numbers across the bottom of the checks. The flow is diagrammed at the left. It begins with payments made by check (*1*). The amount of each such check is credited to the payee's account (*2*). Ultimately, however, the amount must be subtracted from the payor's account. Accordingly the check moves through a combination of three institutions: correspondent banks (*3*), which handle checking accounts for some banks and provide geographic coverage for others; clearinghouses (*4*), which receive the checks banks have credited to their own accounts and sort the checks for distribution to the banks on which they are drawn, and Federal Reserve Banks (*5*), which act as clearing houses. On the average a check in transit is processed by nearly two banks, including the payor's bank (*6*). The machine-readable numbers on checks are shown above. They are printed on checks in an ink containing an iron oxide, so that the numbers are magnetized and can be "read" by sorting machines and computer-input devices. (Increasingly the net transactions among banks are being settled electronically.) On-us fields are at the discretion of the payor's bank (or its correspondent): they identify the payor's account and may record the number of the check itself. The amount field indicates the dollar amount of the check as entered on the check by the payee's bank. The transit field guides the check through the banking system. Its first two digits specify which of the 12 Federal Reserve districts in the U.S. includes the payor's bank. Its third digit specifies a Federal Reserve office in that district (or a special arrangement for collection of funds). Its fourth digit specifies a state in the district (or a special collection arrangement). The remaining four digits identify the payor's bank specifically. Information in the transit field also appears (for manual sorting) at the upper right-hand corner.

The number of CHIPS transactions has increased by a factor of 20 in the first 10 years of the system's full operation. In terms of the dollar value handled its growth has been even greater, amounting to an average annual increase of some 40 percent. So rapidly has the flow of money into and out of business accounts increased that a typical member of CHIPS will process dollar values each day that can be tens of times the total worth of the bank itself. Meanwhile consumer-oriented automatic clearinghouses have been created to handle electronically operations such as the direct deposit of paychecks in an employee's bank account and the payment of periodic consumer bills for mortgages, rent and utilities. In the case of direct deposit, payroll data are transmitted to a clearinghouse, which rearranges the information so that each bank gets the individual payroll payments for the accounts it maintains. Direct deposit, encouraged strongly by the Federal Government for its own employees and for Social Security payments, is growing fairly rapidly; so far the consumer-payment side is clearly less popular.

Overshadowing all these changes has been the growth of bank-sponsored credit cards. Banks were relatively slow to offer credit cards in force. Individual banks had offered cards in the 1950's, and some regional systems evolved late in that decade, but the development of the two national bank systems, called Bank Americard and Master Charge at first, did not take place until the late 1960's. Growth after that was rapid, and the card systems have long since replaced many merchants' credit operations as well as cash and checks.

What has all this meant for banks, their customers and society in general? For one thing, it is clear that without mechanization many of the paper-based systems simply could not have coped with the growth in the use of bank services over the past two decades. Not only would labor costs have risen greatly but also, given the need for the careful checking and balancing of individual entries the banking industry requires, the sheer handling of paper documents would have made it impossible to keep the conduct of transactions timely. The result would no doubt have been some combination of higher prices, poorer service and limited growth. Instead productivity in the processing of checks has probably more than doubled between 1960 and 1980. The growth in productivity attributable to the wire networks has almost certainly been even larger.

In a subtle way mechanization has contributed to a change in the nature of banking. Because of Government regulations that restrict the activities of banks, the banks have lost ground to other financial organizations as intermediaries between those who have money available and those who want to borrow money. For example, large corporations now transact short-term loans with each other rather than conducting the equivalent transactions with banks. The loans are mediated by underwriting and securities companies. Moreover, money-market funds have replaced savings accounts for many individuals. Meanwhile, however, and partly as a result of high capacity, efficiency and low costs, the banks have increased their activity as movers of funds. In the process the operations of the financial intermediaries that now compete with banks have been supported and even facilitated.

Employment in banking has not suffered from mechanization. Because increases in productivity have been accompanied by even larger increases in the demand for bank services employment grew by 50 percent between 1970 and 1980, from slightly over a million to nearly 1.6 million. Much of the current flow of money through banks is a response to high inflation and volatile interest rates, and the flow may drop if a stabler economic environment returns. Regulatory reforms may remove the restrictions banks now face. The industry has nonetheless been restructured, and a complete return of banks to their traditional practices is unlikely.

The distribution of goods has always

UNIVERSAL PRODUCT CODE is the set of thick and thin bars printed on many supermarket items now sold in the U.S. It encodes 12 digits. Six of them, to the left of the "center guard pattern," are each represented by a light space, a dark bar, a second space and a second bar. The other six, to the right of the center-guard pattern, are each represented by a bar, a space, a bar and a space. The arrangement enables the computer at a grocery checkout counter to determine whether the code has been scanned backward by the sensor at the counter. (In that case the computer inverts the data.) The 12 digits have various meanings. The first decoded digit, which also appears in "human-readable form" at the left of the pattern of bars, is called the number-system character. A zero signifies a standard supermarket item. The next five decoded digits (in this case 12345) identify the manufacturer of the item. The five digits after that (67890) identify the item itself. The last digit, which does not appear in human-readable form, serves to confirm that the other 11 encoded digits have been scanned and decoded correctly. It is the smallest number that yields a multiple of 10 when it is added to the sum of the second, fourth, sixth, eighth and 10th decoded digits plus three times the sum of the first, third, fifth, seventh, ninth and 11th digits. Corner markings define the area that should be blank around the set of bars. The set of bars was prepared by the Photographic Sciences Corp.

required financial services; in fact, many bank and insurance practices arose in response to the needs of those who transport goods. The mechanization of transport, however, clearly calls for more nonelectronic equipment than banking does, although transport too makes intensive use of electronic systems. The combination of nonelectronic and electronic equipment can be seen in the recent growth of containerized shipping. Containers themselves are an ancient form of technology, but their current level of service owes much to the availability of telecommunications and computers.

The modern container-ship era started in the late 1950's, when Malcolm McLean acquired the Pan Atlantic Steamship Company, a shipping organization that connected ports in the U.S. Northeast with ports on the Gulf of Mexico and in Puerto Rico. Having previously operated a trucking line, McLean decided to offer a "ferry service" for trucks, but one that left the truck wheels ashore. By having flatbed trailers carry containers overland and by lifting the loaded containers between ship and shore he speeded loading and discharge and could move goods in containers from their origin to their destination. A similar service between the U.S. West Coast and Hawaii was inaugurated by the Matson Navigation Company at about the same time. Both services flourished and others began to emulate them.

The subsequent progress of containerization was difficult. The standardization of container sizes and of the fittings with which cranes lift the containers was an early requirement. Regulation also influenced the pace: Puerto Rican and Hawaiian routes were domestic and relatively unregulated, but U.S. international shipping services were both highly regulated and highly subsidized by the Government. The subsidy mechanism tended to discourage the adoption of container technology; for example, it subsidized U.S. operators for crew costs higher than those of foreign operators but not for the costs of developing more fully mechanized ships and services.

Institutional barriers were also numerous. Shipping has many participants: shippers, freight forwarders (consolidators of cargo who make money from the differential in transportation rates between small quantities and larger ones), overland carriers, insurance companies, longshoremen, pier operators, agents and customs brokers (who are hired to expedite the formalities at the dockside) and the shipping lines themselves. There are likewise many regulators: the Federal Maritime Commission, the Maritime Administration, the Interstate Commerce Commission and the U.S. Customs Service. Each of these parties was affected differently by the introduction of containers, with some gaining advantages and others feeling threatened. Although the net financial effect of containerization was a considerable savings in costs, the distribution of the savings was worked out only slowly.

Containerization offers many benefits. Cargo is better protected from damage and pilferage and so insurance rates can be lower. Handling times and costs are greatly decreased; indeed, in many instances containers can move from their origin to their destination without being opened en route. From the ship operator's point of view the major gain is the far greater utilization of his primary asset: his ships. With cargo-handling rates in port increased by a factor of 10 or more (from about 500 tons per day for conventional ships to 5,000 for container ships) container ships can spend far more time at sea earning money and less time in port, where all they accrue are costs.

To support container services a variety of telecommunications and computer systems are crucial. Since the ships are large, fast and spend little time in port, their cargo manifest is seldom complete when they are ready to leave. Thus manifests are best transmitted by telecommunications from computer to computer rather than being sent by air mail to destination ports. Even more important, it is necessary to keep track of the multitude of containers. Who owns each one? What type of container is it? Where is it? What does it carry, and from where to where? What is its condition? Does it need repairs? Who owes whom how much money for its use or maintenance? Where should it go next when it is empty? Is the supply of empties in a region adequate or inadequate? Where can empties be obtained? Small containerized shipping services can be operated without computers, but the large pools of containers necessary for efficient major operations would become hopelessly confused without computerized control.

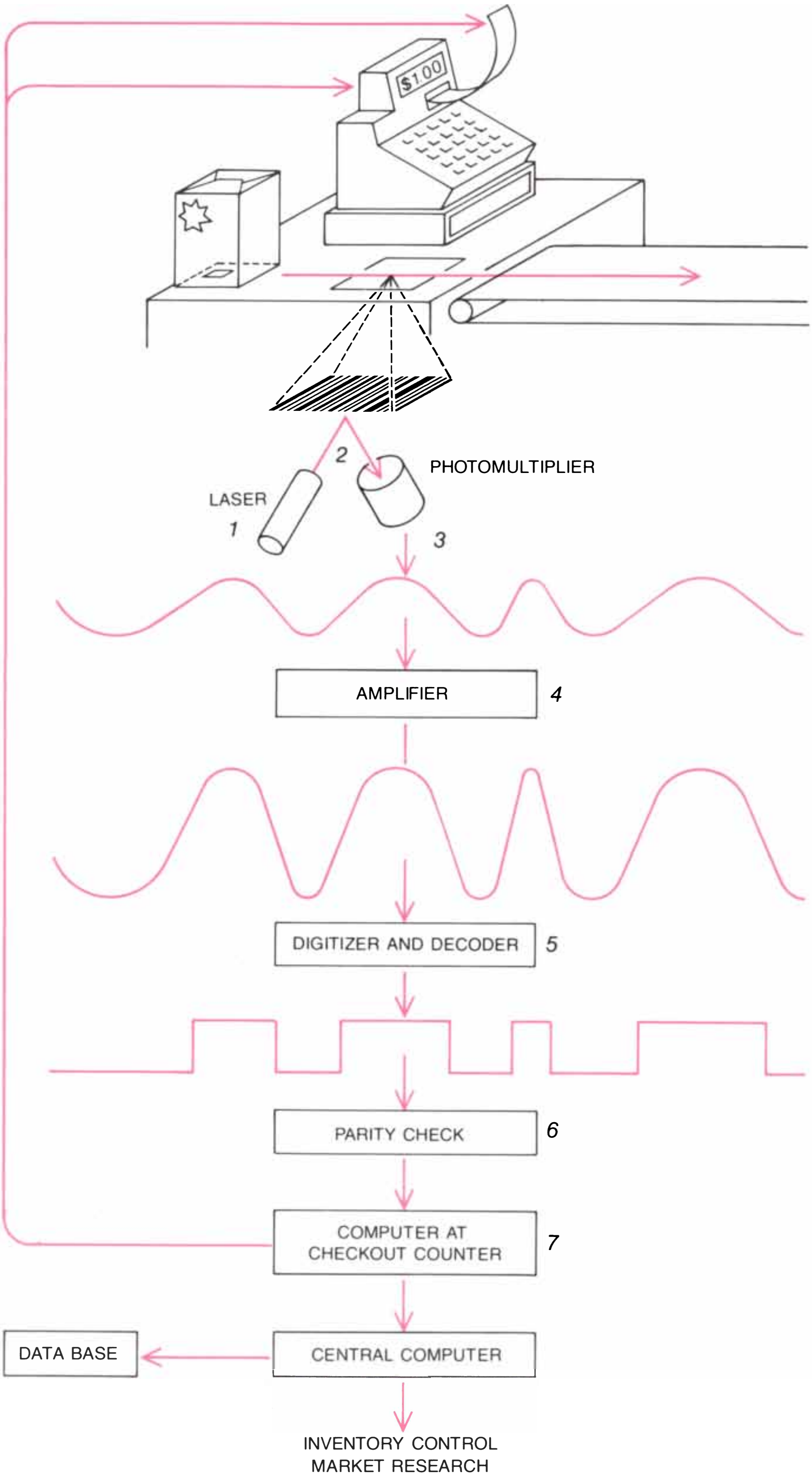
The container ships themselves are increasingly mechanized. Typically the engine room in the newer ones goes unmanned on the night shift, because the instrumentation and control systems on the bridge are adequate for most operations. Crews have dwindled in size (although they remain above the minimum levels set by the U.S. Coast Guard), and because of the small amount of time the ships spend in port crews get long vacations and are given quarters more reminiscent of cruise ships than of traditional freighters. Matching the decrease in port time has been a decrease in the number of berths needed at a port. To be sure, considerable space must be available to marshal and store containers, but this space often is provided at new terminals on the outskirts of port cities. The inner-city waterfront previously devoted to shipping thereby becomes available for redevelopment as commercial, residential and recreational areas.

Since all ocean transportation requires some associated overland movement, containerization has also had an impact on trucks and railroads. Railroads in particular can take advantage of the large flows of cargo arriving on container ships by introducing efficient unit trains that move the containers to major inland destinations. Such services now operate coast to coast in the U.S., where they also are being utilized intensively to deliver bulk cargoes such as coal and ores. The cars making up bulk-cargo unit trains are coupled together for an extended period. The couplings allow each car to rotate about the long axis of the train, so that they can be unloaded by rotation without the labor-intensive operations of decoupling and recoupling, an example of a simple technology having quite impressive results.

New electronic equipment is being applied in all forms of transportation. Computer-based systems are beginning to provide brokerage services that bring together empty trucks and cargo awaiting movement. Microprocessors installed in vehicles now analyze data they get from sensors to improve the performance of all types of engines. They will come to have a role in other forms of vehicle control. In one potential application microprocessors would be given information on the "consist" of a train (the order and weight of each car in the train) and use it to guide the train's braking. The results would likely be lower fuel consumption and less wear and damage to both the train and its cargo. Up to now, however, the most widespread application of new electronic systems undoubtedly has been in air transportation.

Consider electronic reservation systems. The first was introduced in 1963 by American Airlines, Inc. It was devised in a joint effort with the International Business Machines Corporation. Before then the airlines employed massive paper-based systems to keep detailed passenger records and had electromechanical display boards in their larger reservation offices to show available seats on planes. The displays were hard to read from a distance; in fact, agents sometimes had to rely on binoculars. The correlation between paper records and electromechanical ones often was quite poor. Between 1960 and 1980 the number of passengers on U.S. airlines grew by a factor of five. The speed, accuracy, ease of use and cost efficiency of electronic reservation systems clearly facilitated this growth. Since air transportation was an expanding industry, employment in it also increased (by 15 percent between 1970 and 1980).

More than most activities, transportation must be viewed as a system, since it often shunts goods from one mode of conveyance to another as it takes them from origin to destination. This suggests that the deregulation of transportation now under way in the U.S. will yield fewer and larger companies, with some of them operating in several modes. It seems likely that mechanization will accelerate the process, since the organizations best able to exploit the benefits of mechanization will usually be those with a degree of control over the entire system of moving goods rather than just one mode of it.



PRODUCT CODE IS SCANNED at the grocery checkout counter by a beam of laser light (*1*). The light reflected from the spaces between successive bars in the code (*2*) is converted into a continuous (analogue) electrical signal (*3*), which in turn is amplified (*4*) and "chopped" into a discontinuous (digital) signal (*5*). The latter signal is decoded, and the calculation of the 12th, or modulo-check, digit (*6*) confirms that the decoding is correct. Then a computer at the checkout counter (*7*) employs the decoded data to find in computer storage the price of the item. The decoded data (as input to a central computer) also guides inventory control, reordering, market research and the allocation of shelf space in stores. Bar codes of one type or another are now in service on library books, paperback books, magazines, order envelopes for photofinishing, ski-lift tickets, packages handled by delivery services and bags of blood in blood banks.

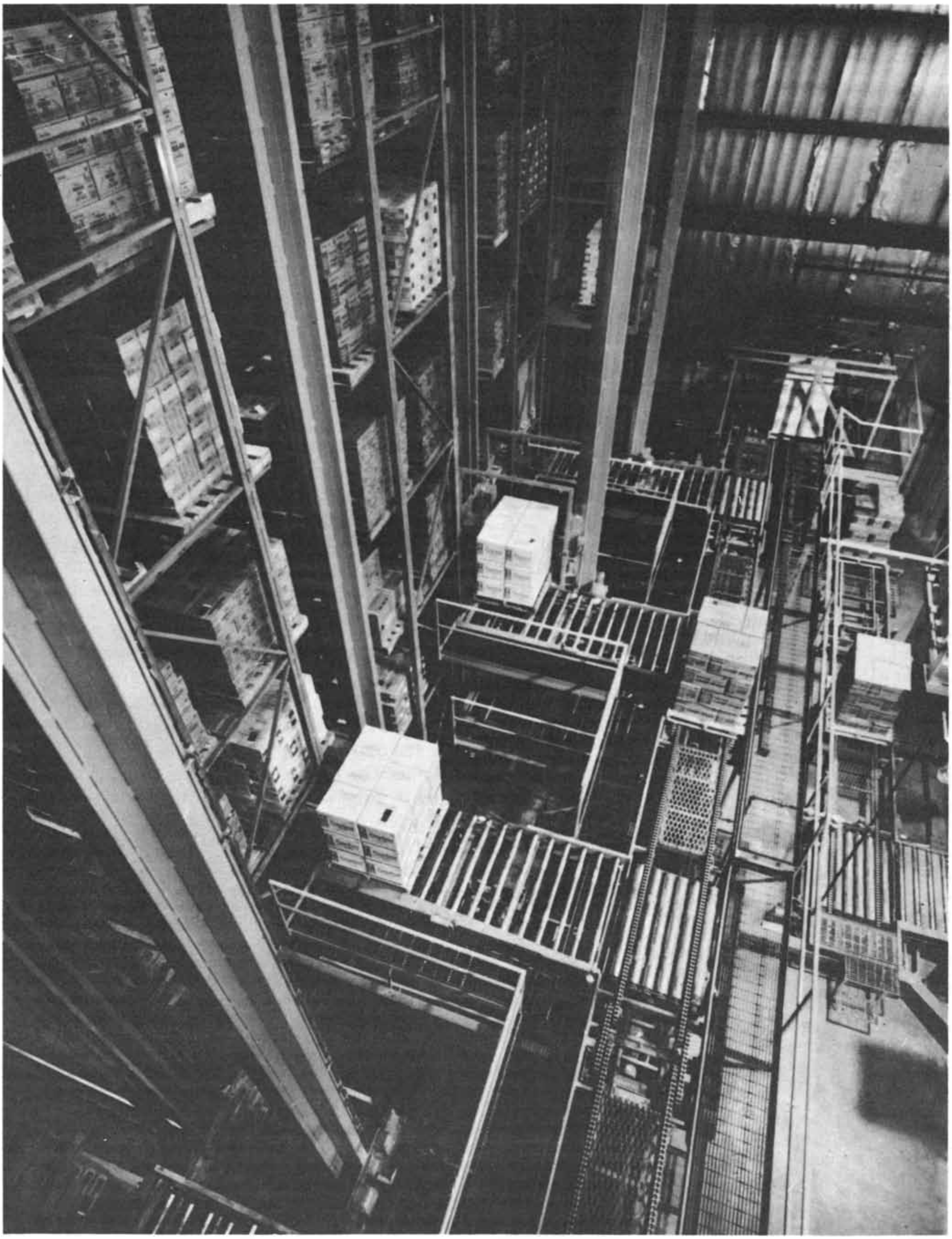
In each aspect of the final distribution of goods (that is, in wholesaling, warehousing and retailing) a variety of types of mechanization are in progress. An example in wholesaling is intercompany electronic-data interchange. Here the intent is to mechanize all aspects of order processing, including not only the transmission of orders to sellers but also the presentation to buyers, in electronic form, of current information on prices, discounts, special offers and the like. The technology is based on now-standard telecommunications networks connecting the computer terminals of the participants, but once again the critical requirement is for standardization.

The requirement arises because individual businesses usually have their own format for preparing price lists, orders and invoices. This creates no problems for people but presents major difficulties for computers. Usually an agreement on standards and formats is reached by trade associations. For example, the Food Marketing Institute, the Grocery Manufacturers of America, Inc., and four other trade organizations have cooperated in developing standards for transactions among distributors, brokers and manufacturers of food. These standards make up the Uniform Communications System (UCS) for the grocery industry. A slightly different approach is being taken for transportation documentation, an aspect of commerce that includes tariffs, manifests, control documents and arrangements for billing and payment. In this case the effort is being spearheaded by the Transportation Data Coordinating Committee, a nonprofit organization supported by dues from shippers, carriers and other members. The approach most often taken in all these efforts has been to standardize communication formats and protocols so that each participant is then able to develop computer programs that will translate between his private format and the communication standard.

In warehousing computers serve a wide variety of record-keeping and scheduling activities. A particularly valuable application is maintaining records of the location of items in storage. This makes possible random storage location, which can be almost twice as efficient as dedicated storage in utilizing the space in warehouses. Another major application is the mechanization of handling operations. The possibilities include aids to essentially manual operations by means of fork lifts and similar equipment that incorporate sensors and microprocessors; operator-controlled but nonetheless semiautomatic order-picking systems, and completely mechanized order-picking systems that can include automatic palletizers and depalletizers, devices that move cartons onto and off portable platforms. Fully automatic specialized warehouse systems were designed as early as 1958, but most of the efforts since then have been devoted to semiautomatic systems because such systems retain greater flexibility for responding to changes in the sizes and shapes of the objects being handled in the warehouse.

In retailing the focus of mechanization has been the cash register and other point-of-sale systems. The retailing of food offers the best example, largely because of the introduction of the Universal Product Code bars (UPC). Like the machine-readable numbers on checks, they are an instance of standardization for the sake of mechanizing the input of data for electronic processing. UPC bars are the set of thick and thin lines now printed on essentially all prepared-food items. At the checkout counter they enable the clerk to identify each purchase to an electronic terminal by passing the item over a photoelectric laser scanner built into the counter. The terminal then retrieves the price of the item from the store's central computer and prints it on a sales slip. At the same time the purchase record can be entered in an automatic inventory control and reordering system. That system in turn can produce data for market research, cost control in the store and shelf-space allocation. The least popular aspect of UPC is the display of prices. The merchant wants to post prices only on the shelves where items are stocked and save the labor cost of having them stamped on the items themselves. In some states, however, the merchant is being required by law to continue putting the price on each item. Nevertheless, the product-code systems are cost-effective, and after a slow start they are spreading fairly rapidly.

Other forms of mechanization in stores are quite common. Terminals have been developed to validate checks that a customer wants to cash by searching a data base to see if any of his previous checks has ever "bounced." Still other forms of mechanization are envisioned. Technically feasible, but not yet in significant service, is a terminal at the checkout counter that is connected to a local bank network. By inserting a plastic card known as a debit card the customer can directly debit his checking ac-



MECHANIZED WAREHOUSE in Hatboro, Pa., is controlled by computers; it stores and retrieves pallets (portable platforms) that bear nonprescription pharmaceuticals (chiefly Formula 44 cough medicine and Lavoris mouthwash) manufactured by the Vick Chemical Company. When goods are being stored, the conveyor at the right in the photograph brings pallets (with their loads) to any one of seven aisles; there it transfers each pallet to an S/R (storage/retrieval) machine, which is also called a stacker. The stacker carries the pallet down the aisle, raises or lowers it and shuttles it into a storage cubicle. The stackers, 65 feet high, move among 14,000 cubicles; the aisles are 390 feet long. Each cubicle can bear a load of 2,500 pounds. The warehouse was constructed by Hartman Material Handling Systems, Inc.

count by the amount of a purchase rather than paying for that purchase in cash or with a check.

The last aspect of commerce I shall touch on is telecommunications. It is an aspect of high importance. For one thing telecommunications is one of the fastest growing industries in the world. It has a range of recognized technical alternatives and potential applications that will take several decades to fully exploit. (The telephone network is so extensive that changes cannot come quickly. Imagine the effort that would be required to extend fiber-optic lines into every household and connect them to produce a visual-communication system.) At the same time the availability of adequate telecommunications is a prerequisite for many of the forms of mechanization described above.

Without a long history of incremental mechanization the telephone service we accept rather casually today would long since have become uneconomic or impossible to maintain. The most obvious episode in this history was the introduction of the dial system, which took the labor of establishing a telephonic connection between two parties and transferred it from the telephone operator to the caller. Over the years the dialing system has been expanded in geographic scope to both national and international operations. Moreover, the efficiency of long-distance operations has been enhanced by the installation of computer-based systems for recording calls and mechanizing the preparation of telephone bills. Within central telephone offices a series of technical advances has marked the transition from electromechanical switches to solid-state ones. The newer switches have lower maintenance requirements, are faster, have better transmission characteristics and more efficiently collect and maintain data for usage analysis and billing.

Many of these developments are based on sophisticated technology. The telephone system also illustrates, however, that major advances in productivity can be made with quite simple devices. Originally all telephone installations were "hard-wired," that is, the telephone lines were more or less permanently connected to the instruments. Then in the 1960's telephone companies introduced plug-in extension telephones. They nonetheless required that at least one hard-wired telephone be installed at each service number. More recently practice has changed further: the telephone wiring now put into houses has universal sockets that enable users to install their own telephones. Although this last change reduced pressure from manufacturers selling equipment designed to interconnect with telephone-company equipment, a major motive was the growing resistance of Government regulators to granting rate increases to cover escalating telephone-installation charges. Many of the telephone companies have now developed computer data bases that record the location of all the wiring and jack sockets in a home, so that people changing their residence can determine their needs in advance and arrange to pick up telephones at a telephone store and install the instruments themselves. A relatively simple set of changes in industry practice has thus allowed labor-sharing and a reduction in installation personnel.

Viewing the mechanization under way in commerce, one is reminded of some of the paintings of the elder Brueghel, with their almost frenetic energy and their display of the diversity and detail of human activities. Commerce is of course only one aspect of life and not the totality Brueghel viewed, and this narrower focus is largely responsible for the similarities I have noted that run through much of its mechanization.

First, although commercial activities provide most of our economic infrastructure, they also must rely on it. A technical innovation cannot be exploited widely if the infrastructure to support it is not available. To be sure, some institutions can take advantage of mechanization better than others, but the others cannot be left out or the process will fail to achieve the universality needed to make it effective. This is the reason the development of formal or informal standards is critical to widespread mechanization whether the standards are formats for data input and telecommunications or specify the size, shape or other characteristics of physical objects. The adoption of standards can trigger an entire set of steps toward mechanization. Still, the introduction of standards is not without risks. Standards introduce a rigidity that may be regretted later if technical advances open up better possibilities. Difficulties also can arise when different standards conflict. Banks have chosen magnetic technology for the input of data; retail stores have chosen optical technology. This may turn out to raise a barrier wherever a combined system is sought.

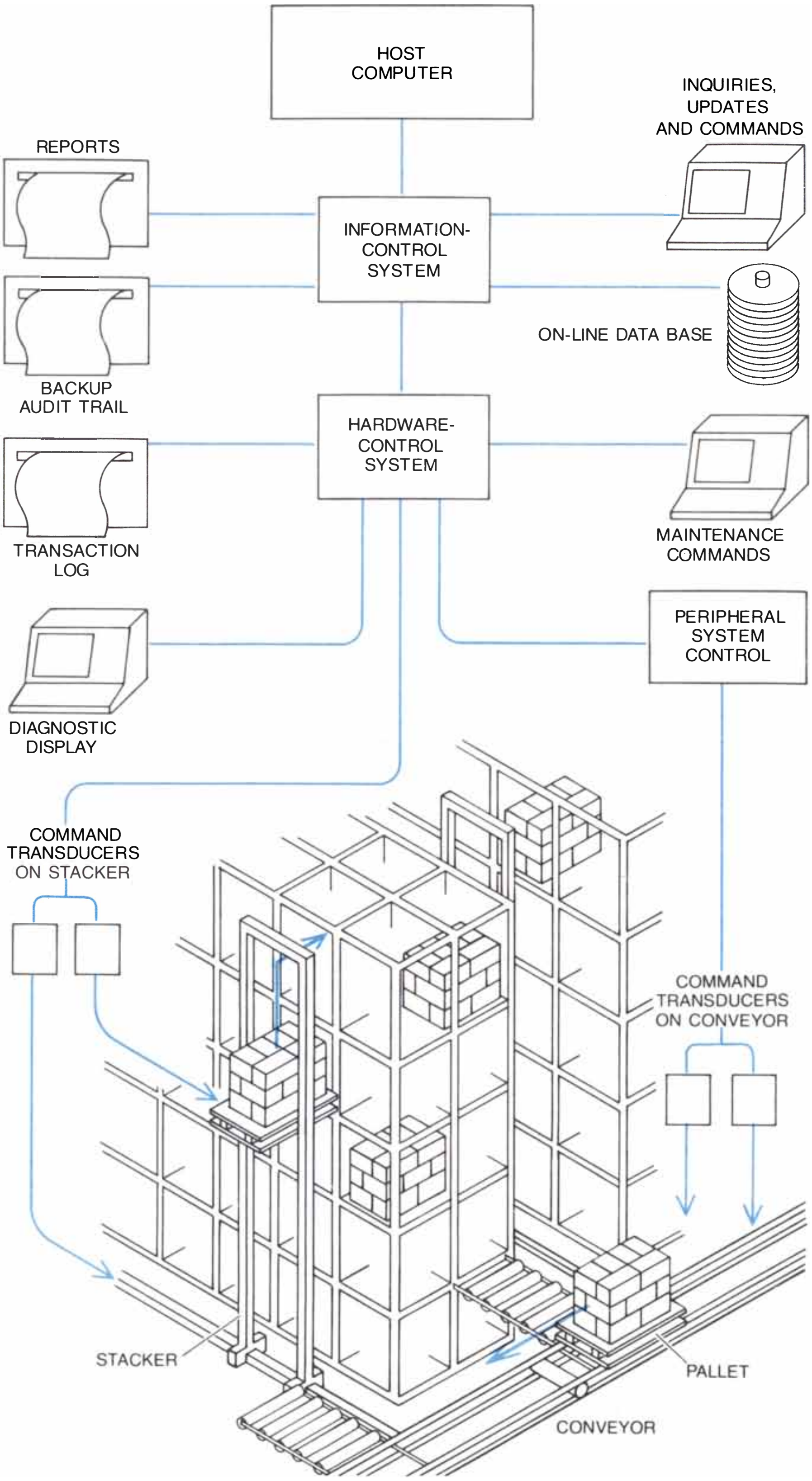
Second, mechanization calls for new institutional relations. Since commerce is a system and its benefits are distributed among many participants, agreement must be reached (or forced) on how the benefits of an innovation are to be shared. Otherwise there may be disincentives for any single participant to invest in the innovation; too few of the benefits may be gained by those who take the risks. The role of government in speeding, delaying or biasing mechanization, and therefore in the new institutional relations, is pronounced. In telecommunications and the financial industries much of the current deregulatory trend in the U.S. can be traced to technical advances that either could not be exploited well in the regulated environment or could be used to bypass the intent of existing regulation. In the latter case the nation was being left with the rules but without the benefits the rules were supposed to encourage.

The benefits of the mechanization of commerce take many forms. Although labor productivity is an obvious example, the results of mechanization have almost always included advances in qualities such as capacity, speed, responsiveness, reliability and economy. These advances have sometimes helped to increase demand, so that displacement of labor has been avoided and employment has actually increased. In any case the level of activity and quality we now take for granted in many industries simply would not have been possible without mechanization.

So much for the benefits; what about the drawbacks? Some of them are related specifically to commerce; others belong to broader concerns about the impact of mechanization on society. In the first category the most publicized concern is the vulnerability of individuals that may result from mechanization in the various financial industries. This concern has already led to consumer-protection legislation covering the loss of credit cards, the actions required when errors in billing are found and similar matters. There remain, however, fears about fraud, theft and invasion of privacy.

There are a variety of measures to alleviate these fears. Some measures are legislative, some are technical. They will of course have a price: higher costs for financial institutions and their customers and more complex demands on consumers for identification during the entry of transactions. So far competition among financial institutions has discouraged individual efforts to implement the technical measures. The greatest current problem is the lack of a formal system for reporting and aggregating data on the frequency and scale of undesirable incidents. They will never be eliminated, but they can be controlled. One can anticipate a continuation of the perpetual war between the locksmith and the thief, now raised to a higher technological level that denies "employment" to the less skilled among white-collar thieves.

Another common concern is that the quality of life is being eroded by the depersonalization commonly associated with mechanization. Plainly the human touch is eliminated when one deals with a machine instead of a human being. Still, many of the examples of mechanization I have described are those where the human touch simply cannot be afforded, so that the real choice is between mechanized service or less service. Overall, therefore, human values may



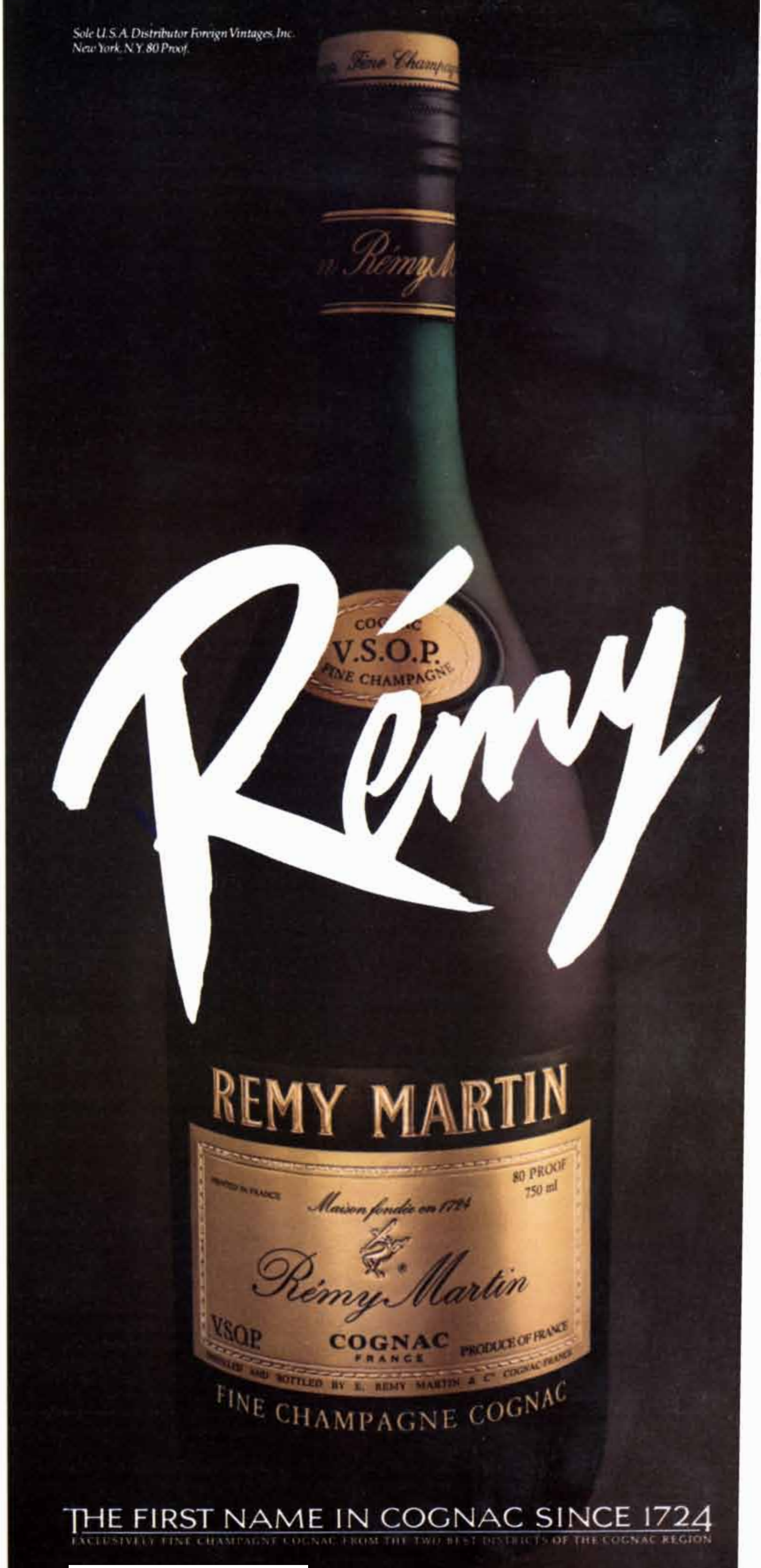
MECHANIZED WAREHOUSE IS CONTROLLED by two linked systems that are often in separate computers. One of them, the information-control system, calculates what might be termed a strategy for storage and retrieval. For example, it divides activity among the stackers, computes the shortest distance to empty cubicles and can select for removal the items that have been stored for the longest amount of time. In addition it continually updates its computerized record of what the warehouse holds. The other system is the hardware-control system. It governs the warehouse's moving equipment: its command signals are transduced into electrical currents that drive the motors on conveyors and stackers. Sensors on the conveyors and stackers in turn send signals to the hardware-control system so that the system can continually update a record of where the moving equipment is. The transaction log and the backup audit trail are printouts of what the systems have done. Often the computer systems that control a mechanized warehouse are linked electronically to a company's central (host) computer.

be served better by accepting mechanization. In some situations, such as when services are needed by people who cannot speak the language of the country they are in, mechanized systems can be designed that are easier to deal with than a person who speaks only the native language. Furthermore, the younger generation quite obviously is not intimidated by the mechanized interface between consumers and electronic systems. The worst concerns probably arise for workers. Many mechanized systems (semiautomatic order-picking devices, for example) tend to isolate individual workers and break up normal social patterns.

More broadly, mechanized systems may actually result in overefficiency. Efficiency is almost always bought at a cost in flexibility and resilience. For example, the U.S. suffered from the Middle East oil crisis because its distribution system for petroleum was so efficient that inventories had been kept at a minimum. This offered little protection against an unanticipated interruption.

Finally, there are the fundamental concerns about displacement of labor. Who is to be displaced and how is the displacement to be handled? When the transition to a mechanized system is slow (as in containerization) or is in a growing industry (such as air transportation or banking), the direct impact is seldom severe; indeed, employment will often increase. When the industry is a mature one and the pace of change is rapid, the problem is not so easily solved. Efforts to retrain the displaced workers generally have a poor record even when the economy is growing rapidly. Most of the workers will feel a justifiable anguish at being severed from their accustomed livelihood. The least skilled workers will suffer disproportionately and are the least able to fend for themselves. This is a broad social problem whose solution will require educational reform and a new emphasis on encouraging the early development by young people of skills that are needed in an increasingly mechanized world. In this regard it is worth noting that future mechanization will probably broaden the range of those affected. Levels of middle management have already been eliminated by some forms of mechanization, and the spread of artificial intelligence may eventually affect even skilled professionals.

So far the demand for new services has been almost open-ended. At some point a fundamental restructuring of business and social life will no doubt come; at present it appears to be more than a decade away. The restructuring will be hard on many people, particularly those whose training and skills limit the types of employment they can seek. The immediate challenge, and a hard one, is to manage the restructuring in a more humane way than was typical of the original Industrial Revolution.



Lockheed knows how.

Advances in research tend to make headlines, but breakthroughs in manufacturing can be as important. The scene above depicts a manufacturing breakthrough that can result in easily fabricated buildings in space. That ingenious advance and others more Earthbound are reported below.

Making building blocks for space.

Someday, astronauts will build a structure in space, and they may well use a new Lockheed manufacturing process.

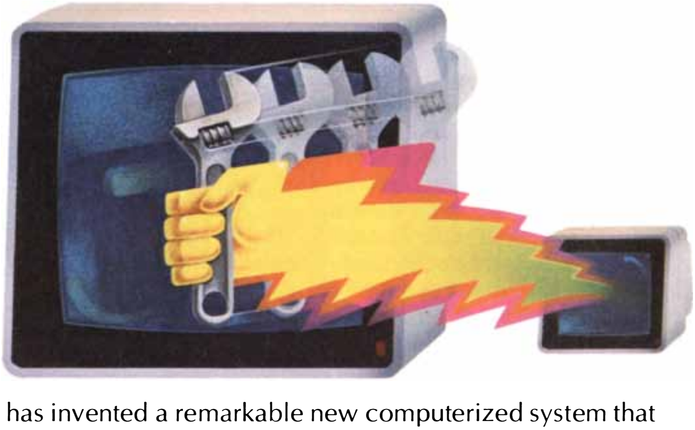
Light and very strong, composites—fibers of graphite embedded in epoxy—are gaining increasing use in aircraft and spacecraft. But making composites usually involves costly "cooking" in a huge oven called an autoclave. However, Lockheed now eliminates that process. It winds graphite fibers around a tube that tapers from 4 to 2 inches over its 8-foot length. Then the tube is heated—this avoids autoclaving—and epoxy is injected around the fibers. Result: an 8-foot structure weighing about 1½ pounds, ⅓ the weight of an aluminum structure of equal strength.

These tapered structures can be packaged inside one another like paper cups to save precious space when transported in the Space Shuttle. A special automated assembly machine designed by Lockheed under contract to the NASA Langley Research Center will enable astronauts to assemble them in space without tools.

Aspiration? Far from it. Lockheed has tested, proven and manufactured dozens of these remarkable structures.

Adding a work force by wire.

To increase productivity—virtually a nationwide goal—you simply make more efficient use of existing staffs and facilities. So logical, yet so difficult. However, Lockheed has invented a remarkable new computerized system that does just that.

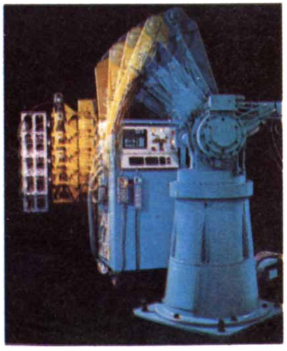


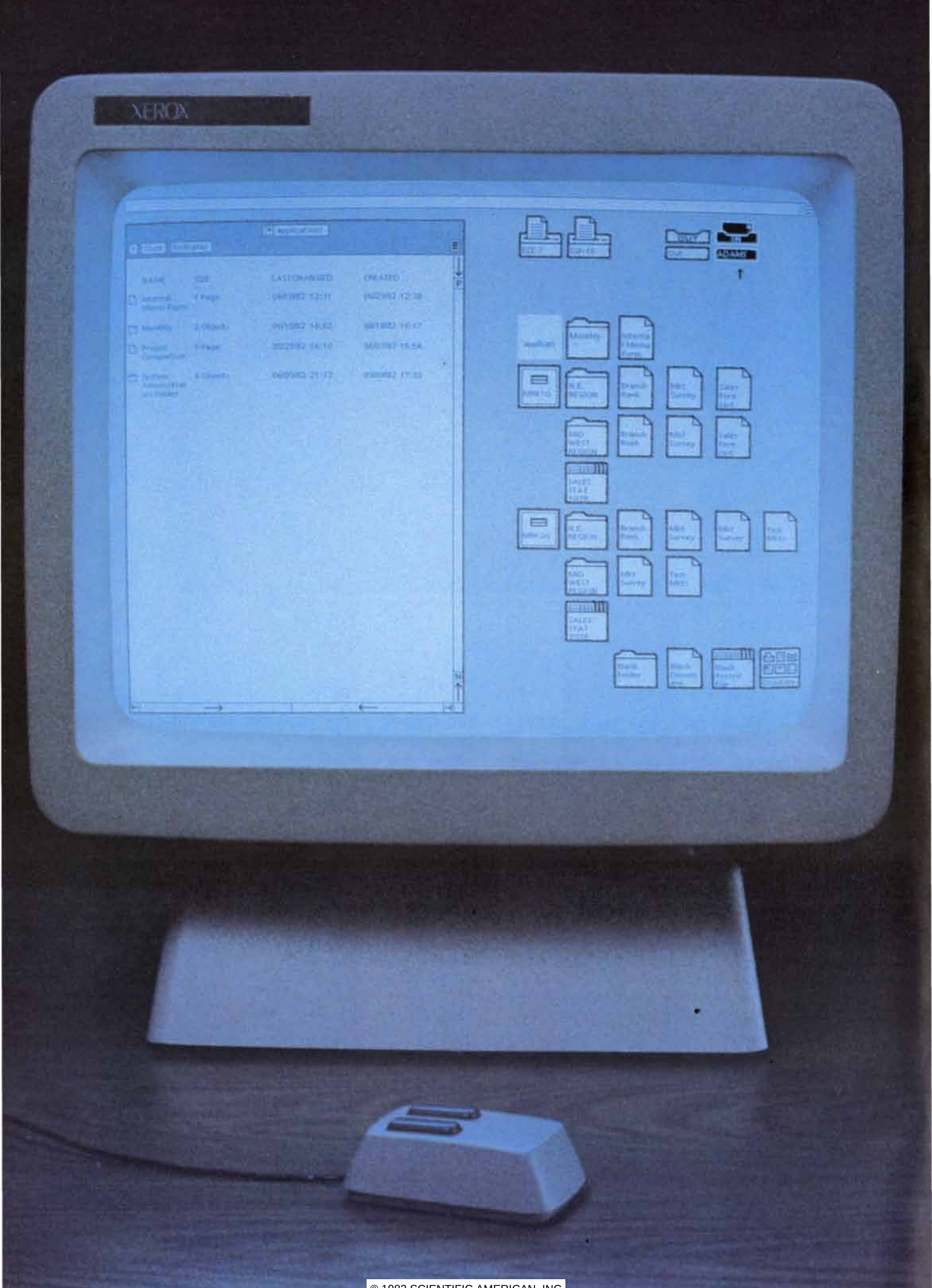
It begins with another unique Lockheed System—CADAM. The computer-based CADAM basically gives engineers a three-dimensional drawing board as big as 48 football fields on which to design parts. CADAM's computer then electronically transmits the design to the plant's manufacturing experts.

Now Lockheed has linked CADAM computers at divisions across the country by a telecommunications network—COMCAM.

If one plant is overloaded, it calls on COMCAM and transmits a CADAM design to another division that can free staff and tools to make the part. This eliminates the cumbersome task of physically moving actual drawings, specifications and tapes from plant to plant. Changes in the design can be made at one plant and instantly transmitted to


make better products.

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The Mechanization of Office Work

The office is the primary locus of information work, which is coming to dominate the U.S. economy. A shift from paperwork to electronics can improve productivity, service to customers and job satisfaction

by Vincent E. Giuliano

Mechanization was applied first to the processing of tangible goods: crops in agriculture, raw materials in mining, industrial products in manufacturing. The kind of work that is benefiting most from new technology today, however, is above all the processing of an intangible commodity: information. As machines based mainly on the digital computer and other microelectronic devices become less expensive and more powerful, they are being introduced for gathering, storing, manipulating and communicating information. At the same time information-related activities are becoming ever more important in American society and the American economy; the majority of workers are already engaged in such activities, and the proportion of them is increasing. The changes can be expected to profoundly alter the nature of the primary locus of information work: the office.

An office is a place where people read, think, write and communicate; where proposals are considered and plans are made; where money is collected and spent; where businesses and other organizations are managed. The technology for doing all these things is changing with the accelerating introduction of new information-processing machines, programs for operating them and communications systems for interconnecting them. The transformation entails not only a shift from paper to electronics but also a fundamental change in the nature and organization of office work, in uses of information and communications and even in the meaning of the office as a particular place occupied during certain hours.

Office mechanization started in the second half of the 19th century. In 1850 the quill pen had not yet been fully replaced by the steel nib, and taking pen to paper was still the main technology of office work. By 1900 a number of mechanical devices had established a place in the office, notably Morse's telegraph, Bell's telephone, Edison's dictating machine and the typewriter.

In 1850 there were at most a few dozen "writing machines" in existence, and each of them was a unique, handmade creation. Typewriters were among the high-technology items of the era; they could be made in large numbers and at a reasonable cost only with the adoption and further development of the techniques of precision manufacturing with interchangeable parts developed by Colt and Remington for the production of pistols and rifles during the Civil War. By the late 1890's dozens of companies were manufacturing typewriters of diverse designs, with a variety of layouts for the keyboard and with ingenious mechanical arrangements. (Some even had the type arrayed on a moving, cylindrical element and thus were 70 years ahead of their time.) By 1900 more than 100,000 typewriters had been sold and more than 20,000 new machines were being built each year. As precision in the casting, machining and assembly of metal parts improved and the cost of these processes was lowered, typewriters became generally affordable in offices and homes. The evolution of typewriter usage was comparable to what is now taking place—in only about a decade—in the usage of office computers and small personal computers.

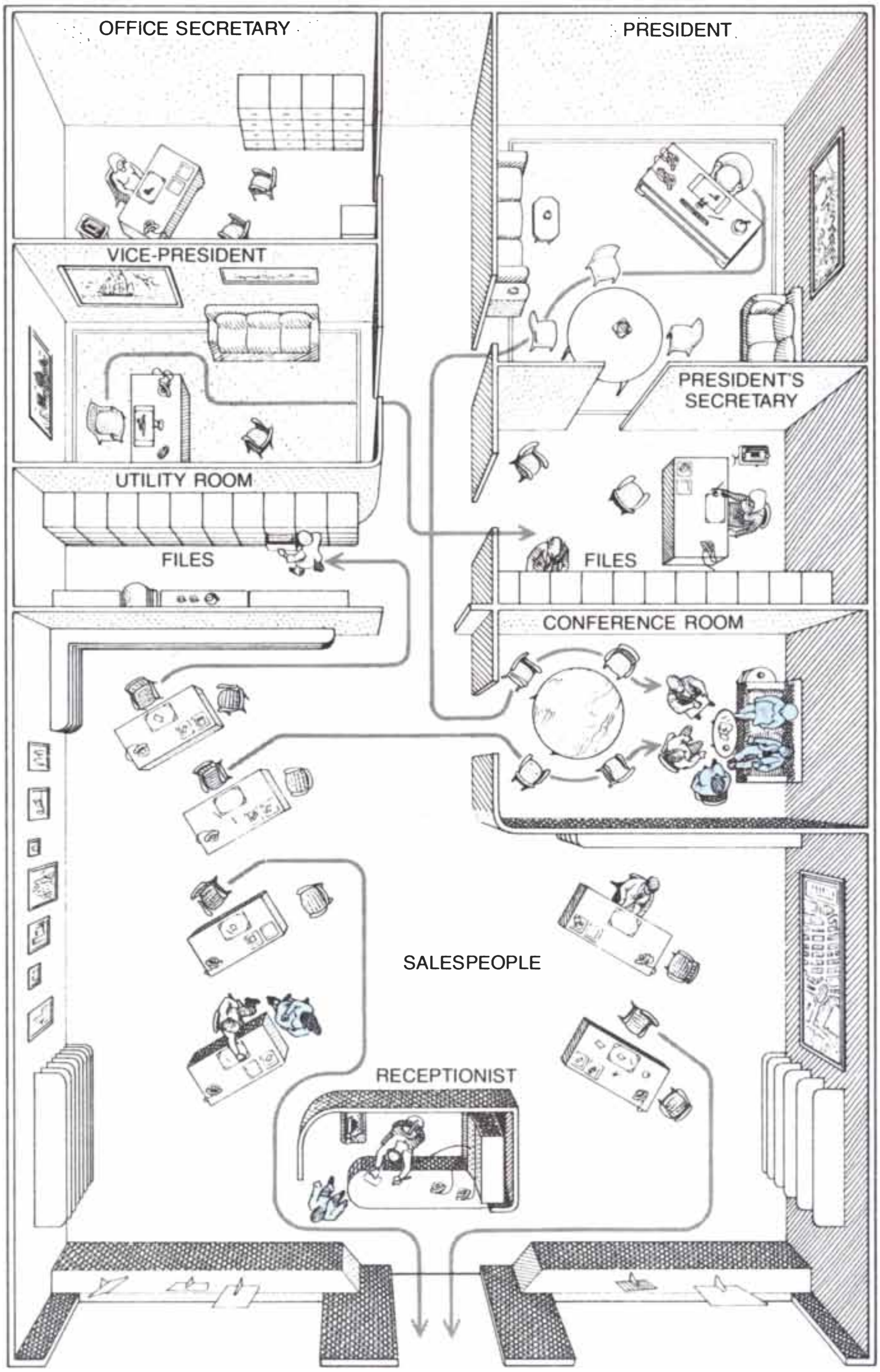
With the typewriter came an increase in the size of offices and in their number, in the number of people employed in them and in the variety of their jobs. There were also changes in the social structure of the office. For example, office work had remained a male occupation even after some women had been recruited into factories. (Consider the staffing of Scrooge's office in Charles Dickens' "A Christmas Carol.") Office mechanization was a force powerful enough to overcome a longstanding reluctance to have women work in a male environment. Large numbers of women were employed in offices as a direct result of the introduction of the typewriter [see "The Mechanization of Women's Work," by Joan Wallach Scott, page 166].

The first half of the 20th century saw a further refinement of existing office technologies and the introduction of a number of new ones. Among the developments were the teletypewriter, automatic telephone switching, ticker tape, the electric typewriter, duplicating machines and copiers, adding machines and calculators, tape recorders for dictation, offset printing presses small enough for office use and data-processing equipment operated with punched paper cards. The new devices were accompanied by a rapid expansion in the volume of office communications and in the number of people engaged in white-collar work.

The first computers in offices were

ELECTRONIC DESKTOP is emblematic of the shift from paper to electronics, the central element in the mechanization of office work. The desktop is displayed on the screen of the Xerox 8010 Star, a personal work station designed for business and professional workers. The Star by itself can serve as a small computer, a word processor and a generator of graphic material; when it is linked to other devices in a local-area network, the Star becomes an information system with access to an organization's electronic files, printers and interoffice and long-distance communications facilities. No special computer skills are needed to operate the work station. The screen shows a number of "icons" (*right*) representing familiar office objects, such as file drawers, file folders, individual documents, an "in" box and an "out" box. The worker sets up his own electronic desktop by manipulating the icons to store documents in folders and drawers, using a keyboard (not shown) and a "mouse" (*bottom*). The mouse is rolled about on the surface of the (nonelectronic) desk to control the position of a pointer on the screen. In the example shown a hypothetical sales manager named Adams has entered his name on the keyboard. His own desktop has been displayed, with a symbol showing there is material waiting in his in box. He has moved the pointer to the in-box icon, pressed the "select" button on the top of the mouse and pressed a key marked "open" on the keyboard, thereby calling up on the screen a list (*left*) of the contents of his in box. Now he can select, read and deal with any of the listed items. For example, he might call up the monthly report, revise it and have it printed.

crude and very expensive by today's standards. By the mid-1960's most large businesses had turned to computers to facilitate such routine "back office" tasks as storing payroll data and issuing checks, controlling inventory and monitoring the payment of bills. With advances in solid-state circuit components and then with microelectronics the computer became much smaller and cheaper. Remote terminals, consisting of either a teletypewriter or a keyboard and a video display, began to appear, generally tapping the central processing and storage facilities of a mainframe computer. There was steady improvement in the cost-effectiveness of data-processing equipment. All of this was reflected in a remarkable expansion of the computer industry. The late 1960's and the 1970's also saw the advent of inexpensive copiers, minicomputers, small and affordable private automated branch exchanges (electronic switchboards), the word processor (the typewriter's successor) and then, toward the end of the 1970's, the microcomputer.

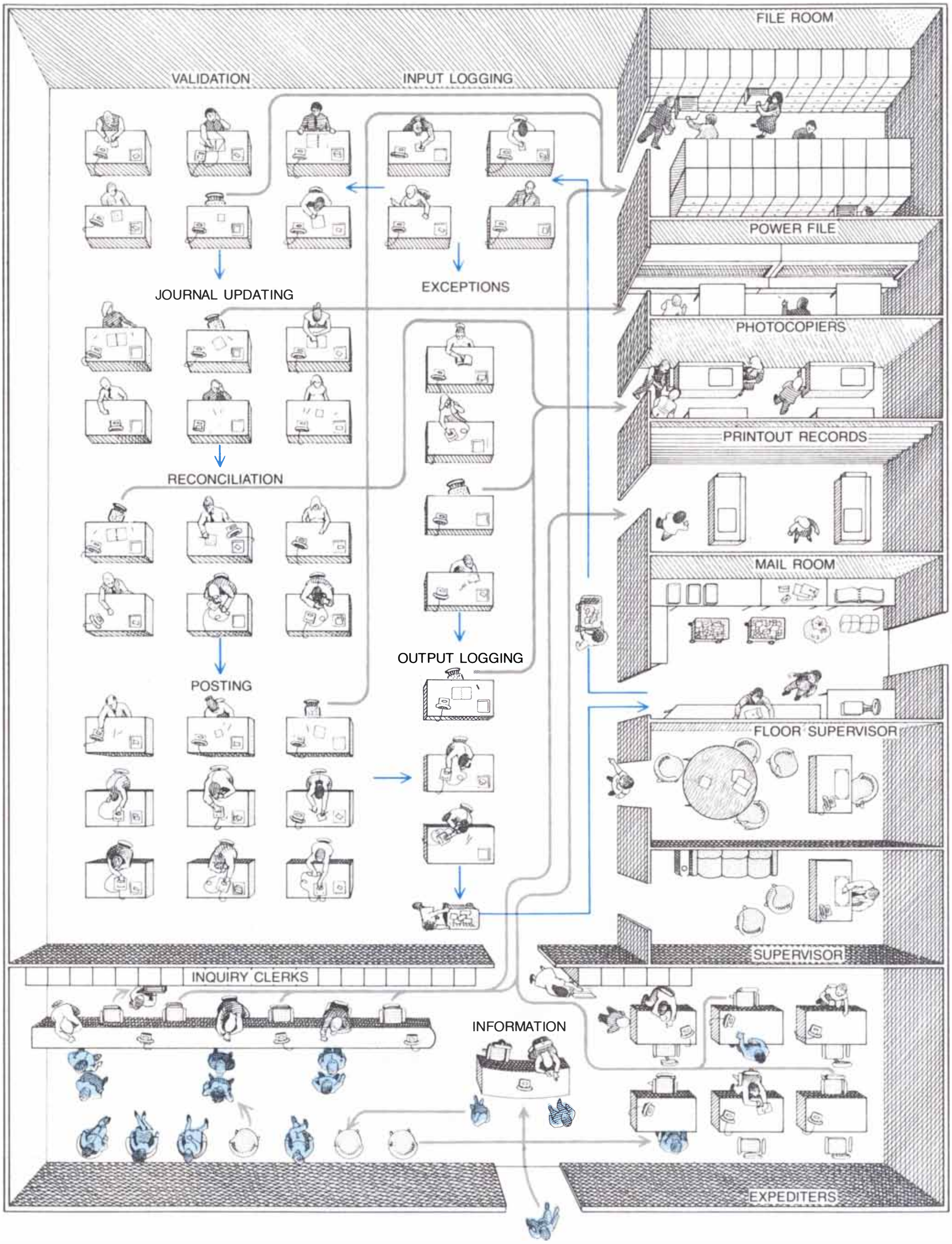


THREE STAGES OF OFFICE ORGANIZATION are defined by the author: preindustrial, industrial and information-age. Preindustrial organization dates back to the mid-19th century but is still typical of most professional, small-business and even corporate-management offices today. It is represented here by a hypothetical real-estate brokerage. There is little systematic organization. Each person does his job more or less independently, moving about as necessary (*gray lines*) to retrieve a file, to take a client to see a property or to attend a meeting where the sale of a house is made final (*color*). Individuals can have different styles of work, and human relations are important. The preindustrial model of office organization can still be effective for some small operations. Conversion to information-age methods is fairly easy.

An anthropologist visiting an office today would see much that he would have seen 25 years ago. He would see people reading, writing on paper, handling mail, talking with one another face to face and on the telephone, typing, operating calculators, dictating, filing and retrieving files from metal cabinets. He would observe some new behavior too. He would see a surprising number of people working with devices that have a typewriterlike keyboard but also have a video screen or an automatic printing element. In 1955 the odds were overwhelming that someone working at an alphabetic keyboard device was female and either a typist or a key-punch operator. No longer. The keyboard workers are both female and male and the typewriterlike devices now accomplish an astonishing variety of tasks.

Some of the keyboard workers are indeed secretaries preparing or correcting conventional correspondence on word processors. Other workers are at similar keyboards that serve as computer terminals. In one office they are managers checking the latest information on production performance, which is stored in a corporate data base in the company's mainframe computer. Economists are doing econometric modeling, perhaps calling on programs and data in a commercial service bureau across the continent. Librarians are working at terminals connected to a national network that merges the catalogues of thousands of participating libraries. Attorneys and law clerks are at terminals linked to a company whose files can be searched to retrieve the full text of court decisions made anywhere in the country. Airline personnel and travel agents make reservations at terminals of a nationwide network. Some of the devices are self-contained personal computers that engineers and scientists, business executives and many other people depend on for computation, data analysis, scheduling and other tasks.

Many of the users of terminals and small computers can communicate with one another and with their home offices through one of the half-dozen "electronic mail" networks now in existence in the U.S. A surprising number of people are doing these things not only in the office but also at home, on the factory floor and while traveling. This article was written with a portable personal computer at home, in a hotel in Puerto Rico and at a cottage in New Hampshire. I have drawn on information from personal files in my company's mainframe computer and have also checked

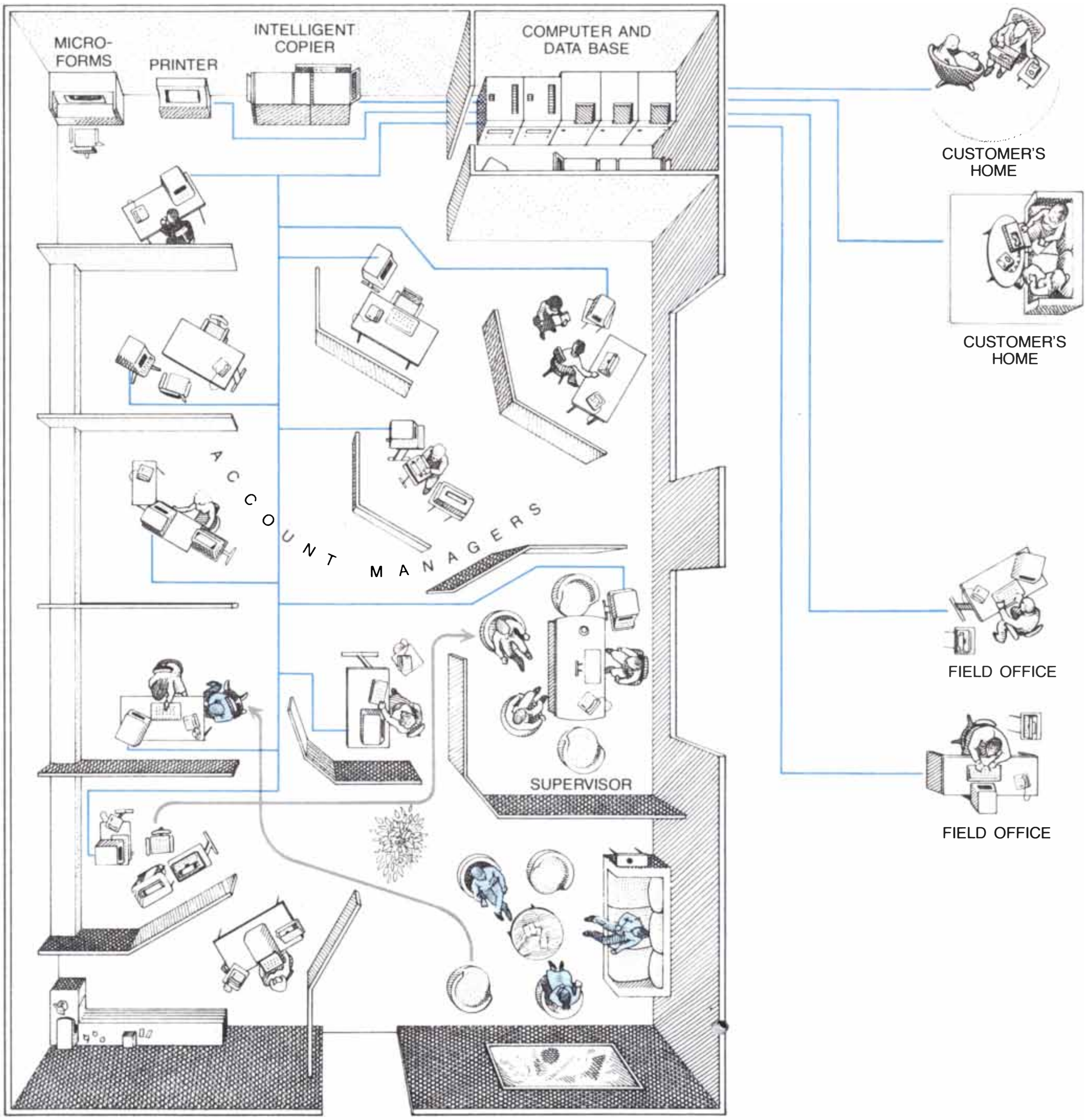


INDUSTRIAL OFFICE, essentially a production line, has been favored for operations handling a large number of transactions, as in this claims-adjustment department of an insurance company. Tasks are fragmented and standardized. Documents are carried from the mail room to the beginning of the production line and eventually emerge at the other end; the flow is indicated by the colored arrows. Successive groups of clerks carry out incremental steps in the processing of a claim; in general they leave their desks only to retrieve files or to examine computer printouts. If clients make inquiries, they are dealt with by clerks who may be able in time to answer a specific question but can seldom follow through to solve a problem. The work is usually dull. The flow of information is slow and service is poor.

parts of the text with colleagues by electronic mail.

What all of this adds up to is a shift from traditional ways of doing office work based mainly on paper to reliance on a variety of keyboard-and-display devices, or personal work stations. A work station may or may not have its own internal computer, but it is ultimately linked to a computer (or to several of them) and to data bases, communications systems and any of thousands of support services. Today the work stations in widest service handle written and numerical information. In less than a decade machines will be generally available that also handle color graphics and store and transmit voice messages, as the most advanced work stations do today.

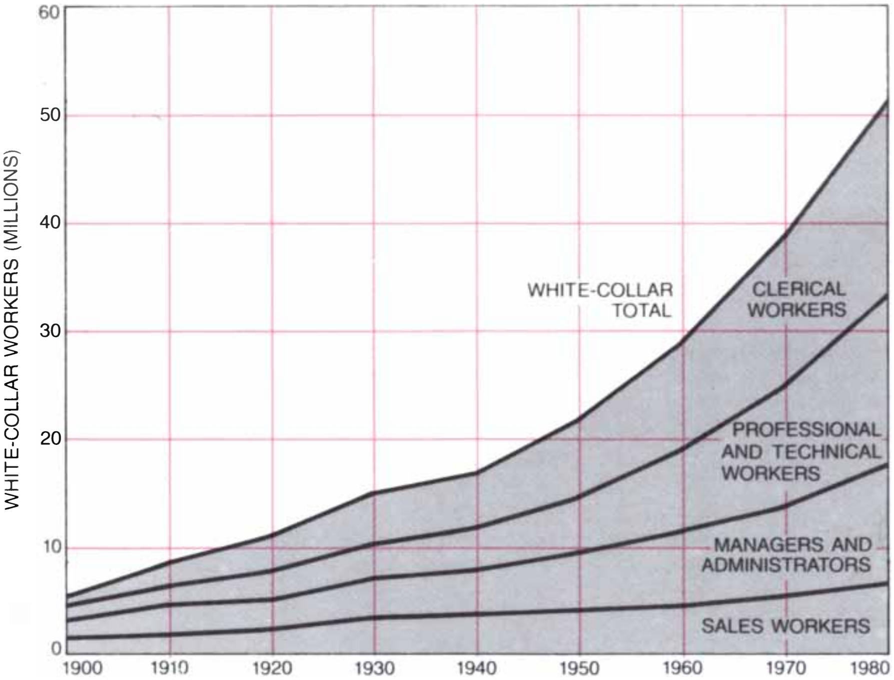
My colleagues and I at Arthur D. Little, Inc., expect that by 1990 between 40 and 50 percent of all American workers will be making daily use of electronic-terminal equipment. Some 38 million terminal-based work stations of various kinds are by then likely to be installed in offices, factories and schools. There may be 34 million home terminals (although most of them may not function as full work stations). In addition we expect there will be at least seven million portable terminals re-



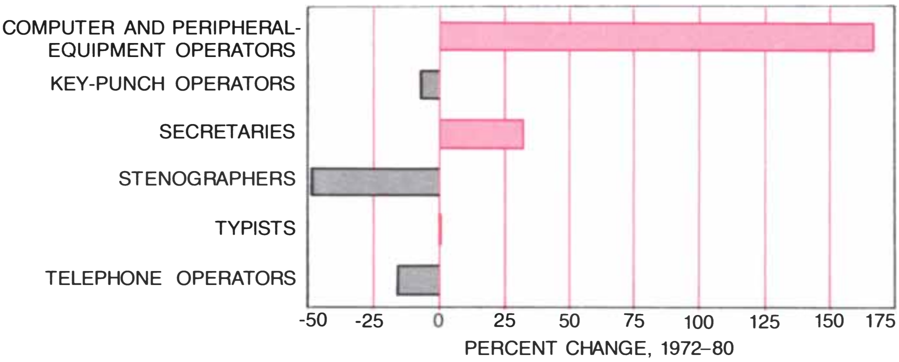
INFORMATION-AGE OFFICE exploits new technology to preserve the values of the preindustrial office while handling a large volume of complex information. The drawing shows an information-age claims-adjustment department. Each adjuster mans a work station, which is linked (*colored lines*) to a computer that maintains and continuously updates all client records. Each adjuster can therefore operate as an account manager, handling all operations for a few clients rather than one repetitive operation for a large number of clients. Necessary action can be taken immediately. Forms are updated and letters are written at the same work station that gives access to stored data, and the forms and letters can be printed automatically. The same facilities are available to adjusters visiting a client's home or working in one of the company's field offices (*right*). The work is more interesting, service to clients is improved and costs are reduced.


3M

WHITE-COLLAR WORKERS now predominate in the U.S. economy. The curves show the percentage of the experienced labor force (from 1900 through 1950) and of all employed workers (from 1960 through 1980) that has been accounted for by workers in white-collar jobs (*colored curve*) and by blue-collar workers, service workers and farm workers (*black curve*).



COMPOSITION OF WHITE-COLLAR GROUP has changed over the years. In 1900 clerical workers were the smallest category; now they are the largest. Most white-collar workers are office workers, and so office productivity has become a matter of increasing concern.



CHANGING NATURE OF OFFICE WORK is reflected in a shift of jobs within the clerical category. The bars show some of the changes from 1972 to 1980. Key-punch operators supply input for older computers. Telephone operators are being displaced by automatic switching.

sembling today's hand-held calculators, most of them quite inexpensive.

Until recently most work stations and their supporting devices and data-base resources were designed to serve a single purpose: to prepare text, access stock-market data or make air-travel reservations, for example. The stockbroker's terminal started out as a replacement for the ticker tape, the word processor as a replacement for the typewriter. The first terminals therefore served as complete work stations only for people who were engaged in a more or less repetitive task.

Now the capabilities of the work station have been extended by developments in the technology of information processing, in communications and in enhancements of the "software," or programs, essential to the operation of any computer system. A variety of resources and functions have become accessible from a single work station. The stockbroker can not only check current prices with his terminal but also retrieve from his company's data base a customer's portfolio and retrieve from a distant data base information on stock-price trends over many years. Millions of current and historical news items can also be called up on the screen. He can issue orders to buy or sell stock, send messages to other brokers and generate charts and tables, which can then be incorporated into a newsletter addressed to customers. It is not only in large corporations that such tools are found. Low-cost personal computers and telecommunications-based services available to individuals make it possible for them to enjoy a highly mechanized work environment; indeed, many professionals and many office workers in small businesses have work-station resources superior to those in large corporations where the pace of office mechanization has been slow.

By the year 2000 there will surely be new technology for information handling, some of which cannot now be foreseen. What can be predicted is that more capable machinery will be available at lower cost. Already a personal computer the size of a briefcase has the power and information-storage capacity of a mainframe computer of 1955. For a small computer an approximate measure of performance is the "width" of the data path, that is, the number of bits, or binary digits, processed at a time. Computational speed can be represented roughly by the frequency in megahertz of the electronic clock that synchronizes all operations in the central processor. Memory capacity is expressed in bytes; a byte is a group of eight bits. The customary unit is the kilobyte, which is not 1,000 bytes but rather 2^{10}, or 1,024. Only three years ago a powerful personal computer had 48 kilobytes of working memory and an

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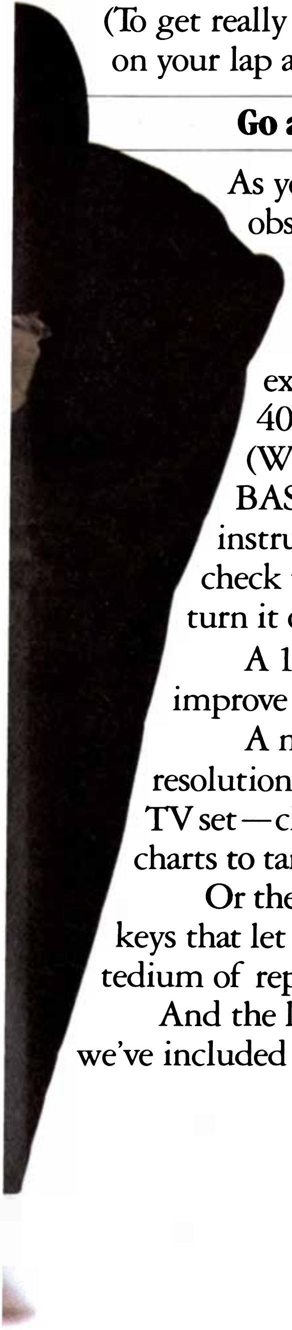

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eight-bit processor running at a rate of one megahertz.

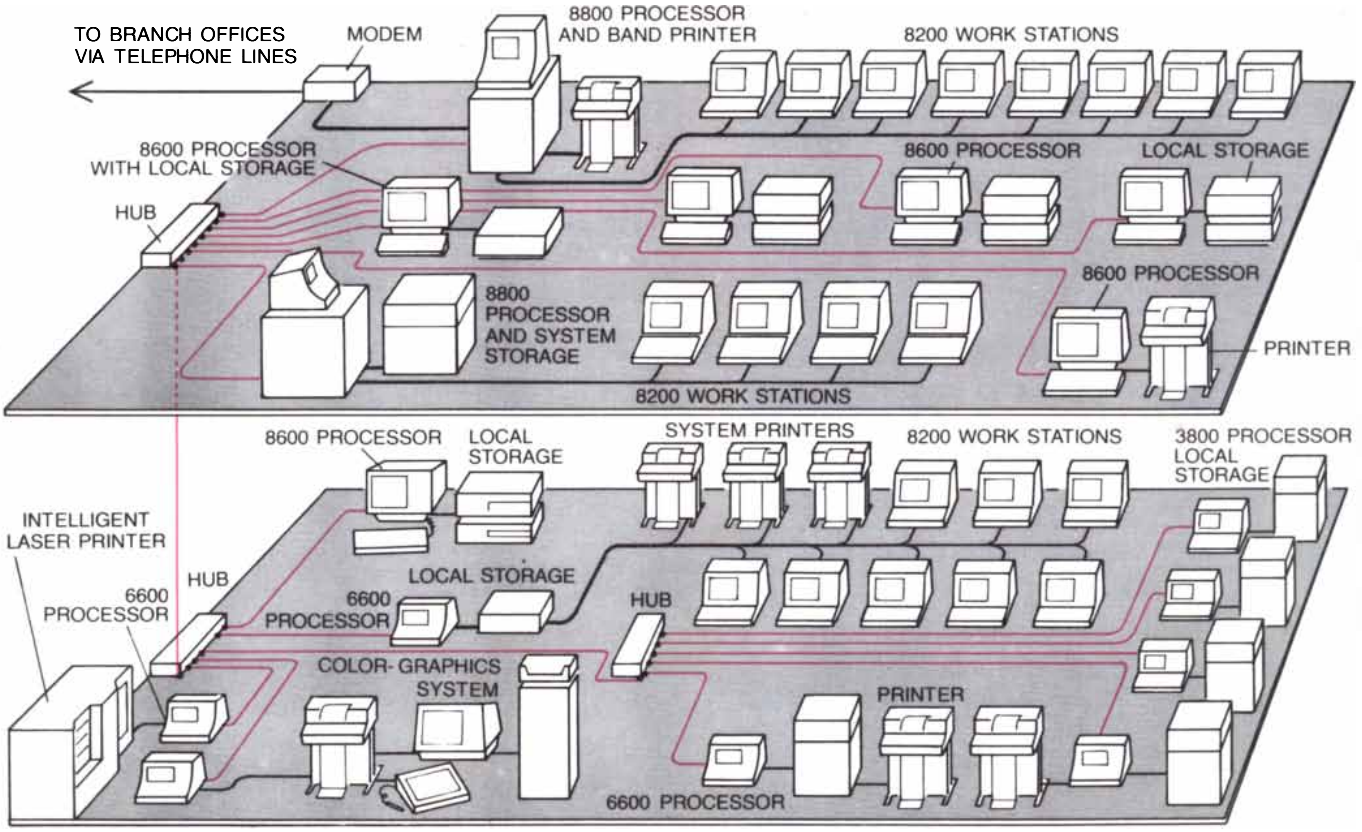
Today about the same amount of money buys a machine with 256 kilobytes of working memory and a 16-bit processor chip that runs at four megahertz or more. Storage capacity and processing power will continue to increase—and their costs will continue to decrease—geometrically. By the year 2000 memory and processing power should be so cheap that they will no longer be limiting factors in the cost of information handling; they will be available as needed anywhere in an organization. The next 20 years will also see the continuing extension of high-capacity communications, of networks for the exchange of information between work stations and other computers and of centralized data banks. Together these developments will provide access to information, to processing capacity and to communications facilities no matter where the worker is or what time it is.

New technology inevitably affects the organization of work. One can define three evolutionary stages of office organization, which I shall designate preindustrial, industrial and information-age. Each stage is characterized not only by its technology but also by its style of management, personnel policies, hierarchy of supervisory and managerial staff, standards of performance and human relations among office workers and between the workers and their clients or customers.

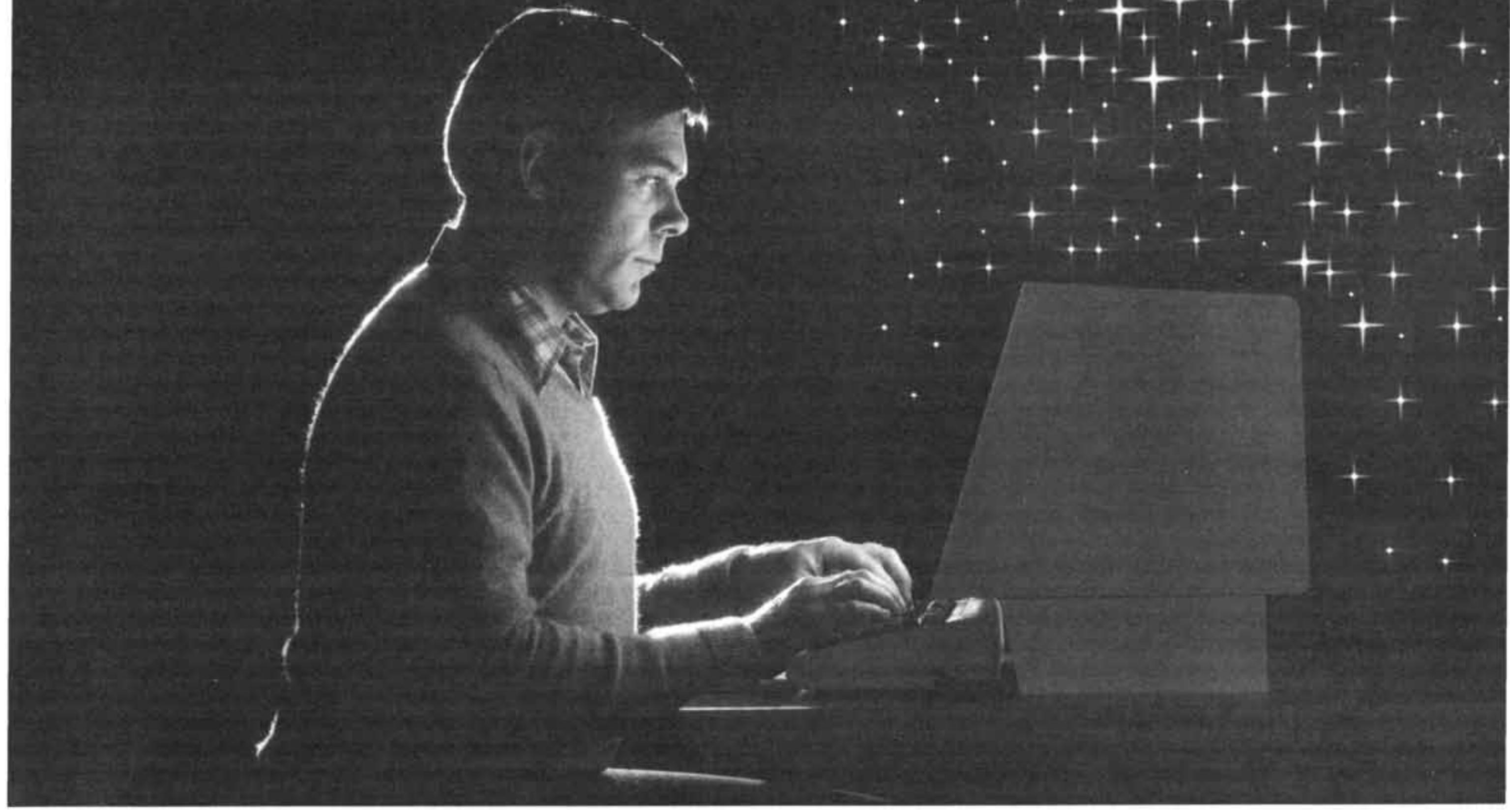
The first two stages correspond to the well-understood artisan and industrial models of production; the nature of the third stage is only now becoming clear. The operation of a preindustrial office depends largely on the performance of individuals, without much benefit from either systematic work organization or machines. The industrial office organizes people to serve the needs of a rigid production system and its machines. The information-age office has the potential of combining systems and machines to the benefit of both individual workers and their clients.

Most small-business, professional, general-management and executive offices are still at the preindustrial stage. In a preindustrial office little conscious attention if any is paid to such things as a systematic flow of work, the efficiency or productivity of work methods or modern information technologies. What information-handling devices are present (telephones, copiers and even word processors) may be central to the operation, but there is no deliberate effort to get the maximum advantage from them. Good human relations often develop among the employees; loyalty, understanding and mutual respect have major roles in holding the organization together. An employee is expected to learn his job, to do what is wanted and needed and to ask for help when it is necessary. Varied personal styles of work shape the style of the operation and contribute to its success.

Preindustrial office organization generally works well only as long as the operation remains small in scale and fairly simple. It is inefficient for handling either a large volume of transactions or complex procedures requiring the coordination of a variety of data sources. If the work load increases in such an office, or if business conditions get more complex, the typical response is to ask people to work harder and then to hire more employees. Such steps are likely to be of only temporary benefit,



LOCAL-AREA NETWORK makes it possible for a large number of work stations in an organization to communicate with one another and to exploit the same data-storage and peripheral equipment. The system shown is the Datapoint Corporation's ARC (for "attached resource computer") network, in which as many as 225 processors (computers) can be linked by a system of coaxial cables (*colored lines*) and interfacing devices. Each processor in turn can be linked by wire (*black lines*) to a number of work stations, storage units or peripheral devices. Each processor has a "resource interface module" (RIM) by which it is connected to a cable leading to a "hub"; each input-output port (*black dots*) on a hub can be connected to a RIM or to another hub. Each RIM has an identification number and attends to any transmission addressed to that number. Traffic is controlled by a "token passing" scheme. Each processor controls the network in turn, taking over to transmit a brief packet of digital signals when it receives a token-passing message from the processor just ahead of it in line. In the system diagrammed here the resources shared by all the devices in the network include magnetic-disk storage units, printers, a generator of color graphics and a modem: a modulator-demodulator that converts digital signals into acoustic signals for transmission over telephone lines. There are also "local" disk units for storing material that is needed only by a single processor.



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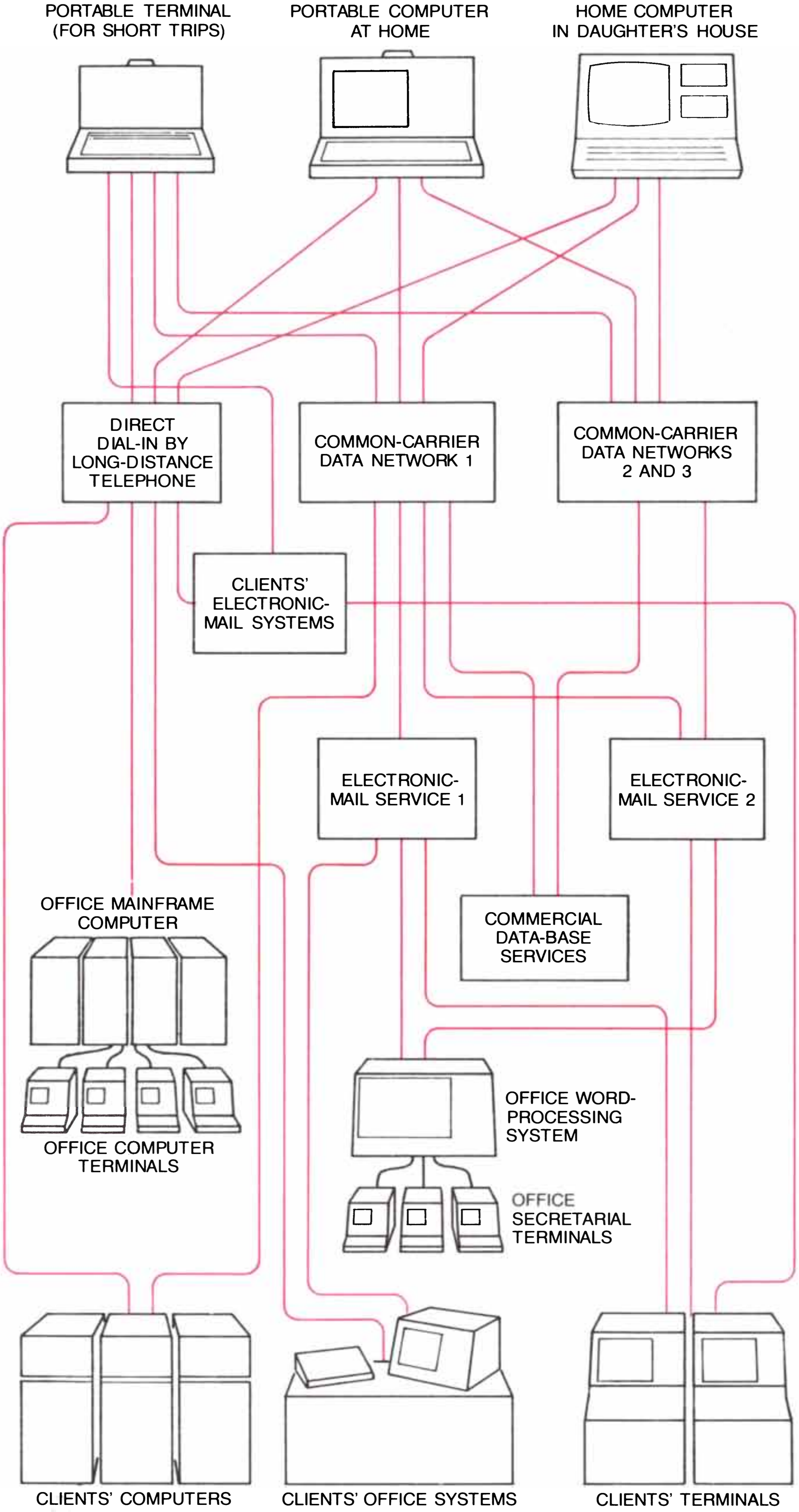
however. Without the help of additional systems or technology, effectiveness and morale may soon begin to break down.

One response to the limitations of preindustrial office organization has been to bring to bear in the office the principles of work simplification, specialization and time-and-motion efficiency articulated for factory work some 70 years ago by Frederick W. Taylor. The result is the industrial-stage office, which is essentially a production line. Work (in the form of paper documents or a folder of papers related to one customer) moves from desk to desk just as parts move from station to station along an assembly line. Each worker gets a sheaf of papers in an "in" box; his job is to perform one or two incremental steps in their processing and then to pass the paper through an "out" box to the next person, who performs the next steps. Jobs are simple, repetitive and unsatisfying. A worker may do no more than staple or file or copy, or perhaps check and confirm or correct one element of data. And of course everyone has to work together during the same hours in the same office to sustain the flow of paper.

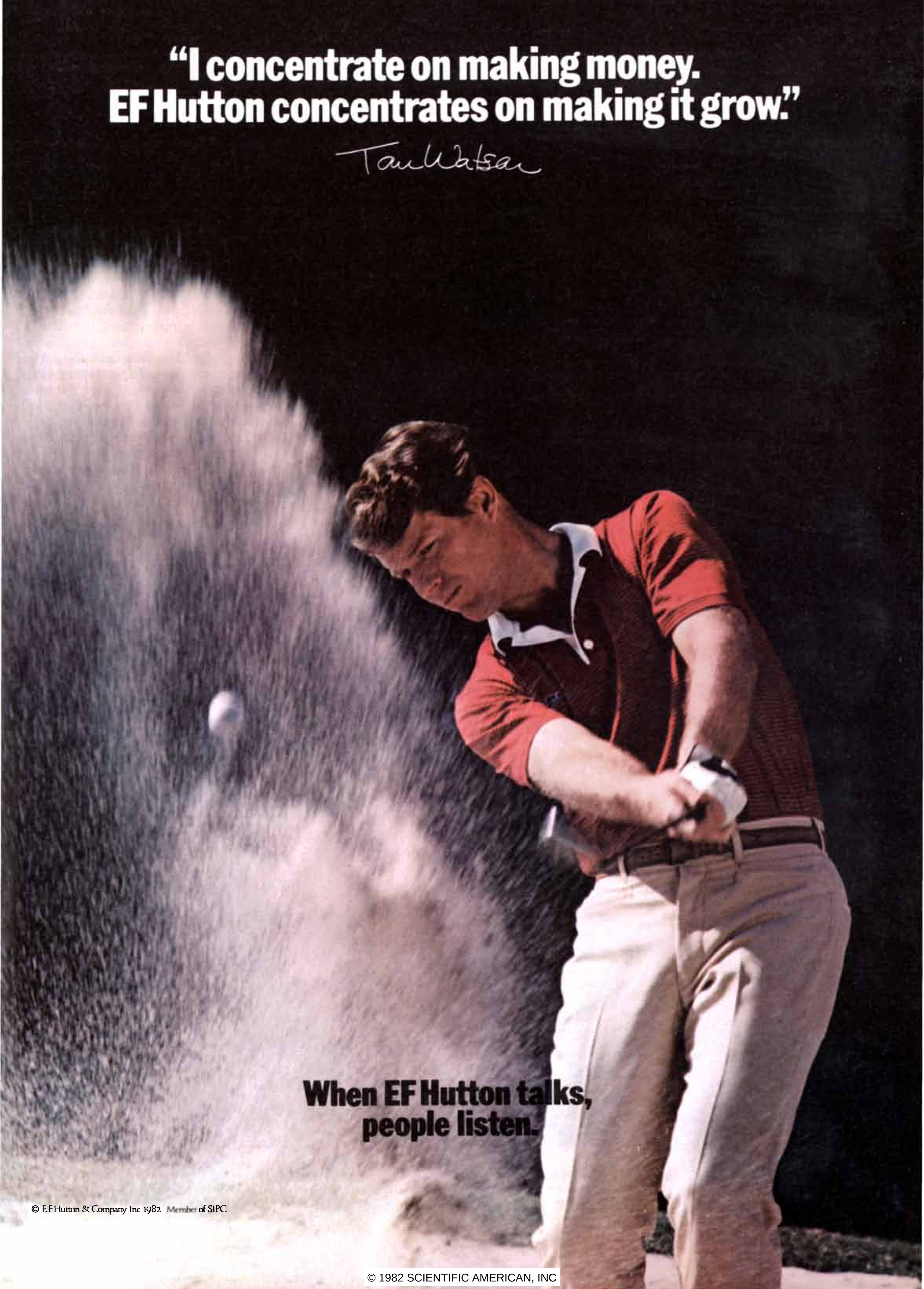
The production-line approach has been considered particularly suitable for office activities in which the main job is handling a large volume of customer transactions, as in sending out bills or processing insurance claims. Many large production-line offices were instituted in the early days of computerization, when information had to be gathered into large batches before it could be processed by the computer; input to the machine then took the form of punched cards and output consisted of large books of printouts. Because early computers could do only a few steps of a complex process, the industrial office had to shape people's tasks to fit the needs of the machine. Computers and means of communicating with them have now been improved, but many large transaction-handling offices are still stuck at the industrial stage.

The industrial model of office organization is based on a deliberate endeavor to maximize efficiency and output. To create an assembly line the flow of work must be analyzed, discrete tasks must be isolated and work must be measured in some way. There is a need for standardization of jobs, transactions, technologies and even personal interactions. A fragmentation of responsibility goes hand in hand with bureaucratic organization and the proliferation of paperwork. Most of the workers have little sense of the overall task to which they are contributing their work, or of how the system functions as a whole.

The industrial office has serious disadvantages. Many errors tend to arise in a production-line process. Because of the subdivision of tasks efforts to cor-



AUTHOR'S PERSONAL NETWORK enables him to work not only in his physical office but in a "virtual" office, which is to say almost anywhere and at any time. His own work station can be a portable terminal or either of two personal computers (*top*) or a work station in his physical office. Communication among physically separated elements of the network is by way of the public telephone system, with digital signals being converted into acoustic signals by portable acoustic couplers or modems. The author can write and edit material on any of the terminals and send it to his office or to clients. He can call up on the screen of a terminal any material stored in memory units at the office or in a commercial data base to which his company subscribes. He can also send and receive messages through two electronic-mail services.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rect errors must often be made without access to all pertinent information, with the result that the errors are sometimes not corrected but compounded. Moreover, production-line operations can be surprisingly labor-intensive and costly. As more people are hired to cope with an error rate that increases faster than the volume of transactions, the cost per transaction increases and efficiency declines.

Effective people do not want to stay in boring jobs; people who do stay often lack interest in their work, which becomes apparent to the customer. Even if workers do their best, the system may defeat them, and customer service is likely to be poor. Because a given item can take weeks to flow through the pipeline it is often difficult to answer customer inquiries about the current status of an account and even harder to take corrective action quickly. For example, a clerk may be able to check a sales slip and agree that a customer's bill is incorrect; in many instances, however, the clerk is able to change the account only by feeding a new input into the production line, with little assurance it will have the desired effect. As a result the billing error can be adjusted incorrectly or can be repeated for several months.

In the mid-1970's the recognition of these limitations, combined with the availability of new work-station information systems, motivated a few progressive banks and other service organizations with a heavy load of transactions to take the next step: they converted certain departments to a mode of operation more appropriate to the information age. The information-age office exploits new technology to preserve the best aspects of the earlier stages and avoid their failings. At its best it combines terminal-based work stations, a continuously updated data base and communications to attain high efficiency along with a return to people-centered work rather than machine-centered work. In the information-age office the machine is paced to the needs and abilities of the person who works with it. Instead of executing a small number of steps repetitively for a large number of accounts, one individual handles all customer-related activities for a much smaller number of accounts. Each worker has a terminal linked to a computer that maintains a data base of all customer-related records, which are updated as information is entered into the system. The worker becomes an account manager, works directly with the customer and is fully accountable to the customer.

Information is added incrementally to the master data base. The stored data are under the control of the worker, who can therefore be made responsible for correcting any errors that arise as well as for handling all transactions. Since information is updated as it becomes available there is no such thing as "work in process," with its attendant uncertainties. An inquiry or a change in status can be handled immediately over the telephone: the sales slip can be inspected, the customer's account can be adjusted and the bill that is about to be mailed can be corrected accordingly.

The design of effective systems and the measurement of productivity are

COMPUTER TERMINALS have a conspicuous place in an office of the Prudential Insurance Company of America in Parsippany, N.J., where claims are processed. Personnel who have identified themselves by entering a password at the keyboard of a terminal can retrieve information on an insured person's policy and claim, modify the information as necessary and add new information to the file.

still important in the information-age office with a large volume of transactions, but the context is different from that of the industrial office. Productivity is no longer measured by hours of work or number of items processed; it is judged by how well customers are served. Are they satisfied? Are they willing to bring their business back? Are they willing to pay a premium for a high level of service?

To the extent that the answers are yes the company gains an important competitive advantage. Even if cost cutting is not the only objective, the company can expect dramatic savings in personnel costs. Staff reductions of as much as 50 percent have been common in departments making the changeover to a work-station system. Those employees who remain benefit from a marked improvement in the quality of their working life.

The benefits of the information-age office are not limited to the transaction-intensive office. A similar transformation can enhance productivity, effectiveness and job satisfaction in offices concerned with management, general administration and research. Most such offices are still in the preindustrial stage. They can be transformed to the information-age stage by the introduction of such person-centered technologies as the work station and electronic mail.

PORTABLE TERMINAL is used by Malcolm Moran, a sports reporter for *The New York Times*, to cover a game at Shea Stadium between the New York Mets and the Montreal Expos. The terminal, a Portabubble 81 made by the Teleram Communications Corporation, is carried on out-of-town assignments by most *Times* reporters. Its magnetic-bubble memory holds between 9,000 and 20,000 words. The reporter can keep notes in the terminal's memory and write part of a story and store it for later transmission; he can have background material transmitted to him from the *Times*. Ordinarily the sports reporter writes his article at the end of the game and then transmits it to the computers at the *Times*. Sending and receiving is by means of an acoustic coupler. To file his story the reporter dials a telephone number and gets a go-ahead signal. Then he puts the telephone handset on the coupler and presses a button; the coupler converts the terminal's digital signals into acoustic signals and the story is transmitted at a rate of 300 words per minute. From the *Times* computers the article can be called up on terminals in the newsroom for editing and sent to the composing room for electronic typesetting.

Once most of the activities of a job are centered on the work station the nature of the office can be transformed in still another way: there is no longer any need to assemble all workers at the same place and time. Portable terminals and computers, equipped with appropriate software and facilities for communication (including the telephone), create a "virtual" office, which is essentially anywhere the worker happens to be: at home, visiting a client or customer, in a hotel or even in an airplane. The remote work station can communicate electronically with the central office and so it extends the range of places where written and numerical material can be generated, stored, retrieved, manipulated or communicated.

The effects of small-computer technology on the locale of work are analogous to those of the telephone. Because of the almost universal distribution of telephones it is not necessary to go to the office to call a customer or a co-worker, but until now it has been necessary to go there to write or dictate a letter, to read mail or to find something in a file. Now the work stations and ancillary electronic devices of an automated office can be linked to external terminals and personal computers. The job is no longer tied to the flow of paper across a designated desk; it is tied to the worker himself. The individual can therefore organize his own time and decide where and when he wants to do his work. Individuals who work best early in the morning or late at night can do so. A project team I have been working with for about a year has members in several East Coast and West Coast cities and rural areas, and we communicate regularly by electronic mail. The cost of the correspondence is about a tenth of the cost of regular mail per item, and it turns out that about half of the messages are generated outside of offices and outside of conventional working hours.

What will happen to the physical office? It has its virtues, after all. The office provides a home for organizations, a place for people to come together face to face and a work-oriented environment away from home. Many people need the structure of an office schedule; they like (or at least they are accustomed to) compartmentalization of the day and the week into time for work and time for other activities. Another role for the office is to house centralized forms of communications technology, such as facilities for video conferences, that are too expensive for the home. For these reasons and others I think the physical office will remain a part of working life, at least for as long as I am working. There will be continuing change, however, in how often some workers go to the office and in why they go there.

Many powerful factors are operating together to propel the transformation of office work. A complex set of feedback loops links economic and social change, new developments in information technology, the widespread adoption of the technology and the introduction of the new office organization the technology makes possible. The large number of information workers, for example, stimulates interest in enhancing their productivity. The concern for productivity serves to increase demand for technologies that can reduce the cost of handling information. Thus several trends reinforce one another to generate an ever stronger market for information products and services. The infiltration of the new devices into the workplace in turn creates an environment in which working electronically is the normal expectation of the worker.

Economics is a major factor. It is becoming far cheaper to communicate electronically than it is to communicate on paper. The transition to word processing from multidraft secretarial typing can reduce secretarial costs from more than $7 per letter to less than $2. Even more dramatic savings are associated with electronic mail, which can bring the cost of sending a message down to 30 cents or less. Electronic filing, in which a "document" is stored and indexed in a computer memory, brings further savings. (The highest-cost activities in manual correspondence are making multiple copies, filing them and retrieving them.) Such obvious reductions in cost are overshadowed by the savings in the time of managers and executives, the largest element by far in the cost of running an office.

The savings are becoming more significant each year as the cost of the electronic technology is reduced. For example, fast semiconductor memory is a tenth as expensive now as it was in 1975; the cost will drop by another factor of 10 by 1995. The result has been to bring into the individual consumer's price range information-handling capabilities that only a few years ago called for very expensive equipment.

As the market for mechanized work stations expands, more money is invested in research and development for communications, electronics, software, office-mechanization systems and the like. The time span between the development, introduction and obsolescence of a product becomes shorter. Each year brings a new generation of semiconductor devices; each generation makes possible a new set of applications. The dramatic improvement in products in turn builds demand for them and strengthens the trend toward office mechanization.

Whether a company's business is in farming, mining, manufacturing, transportation or retailing, its management, marketing, distribution and other operating controls are basically office-centered, information-handling activities. As the number of blue-collar workers decreases, the proportion of white-collar workers even in manufacturing organizations continues to increase. In virtually all commercial enterprises one finds executives, managers, clerks and secretaries; in most organizations there are also more specialized information workers, such as engineers and scientists, attorneys, salesmen, librarians, computer programmers and word processors. These people constitute the human-capital resources that can make an information-intensive economy viable.

Yet a tendency to think of white-collar workers in offices as support personnel, outside the economic mainstream, has tended to inhibit the transformation of office work. Physical activities that produce food, minerals and manufactured goods have been regarded as the only truly productive ones, whereas the handling of information has been considered necessary but essentially nonproductive. This way of looking at things (which may have been appropriate in an industrial society) persists today, even in the minds of economists who call for the "reindustrialization of America." It deeply affects the thinking of corporate management.

Even though most work in American society is information work and most such work is done in offices, the benefits of an increase in the productivity of office workers are not always within the field of view of managers. For those who retain a preindustrial view of office organization the very concept of productivity seems irrelevant or inappropriate in the context of offices or information work. Those who have an industrial-office orientation tend to focus on laborsaving measurements; the installation of new technology and a system for exploiting it is evaluated only in the context of cutting visible office costs.

It is in offices that the basic decisions are made that determine the cost-effectiveness of an entire organization. The office is the place where the timeliness of a decision or of a response can have immense consequences. If the office is ineffective, the organization must be ineffective. As it happens, moreover, a high degree of mechanization of the kind described in this article is much less expensive in the office than analogous mechanization is in the factory or on the farm.

The mechanization of office work is an essential element of the transformation of American society to one in which information work is the chief economic activity. If new information technology is properly employed, it can enable organizations to attain the following objectives: a reduction of information "float," that is, a decrease in the delay and uncertainty occasioned by the inaccessibility of information that is being typed, is in the mail, has been misfiled or is simply in an office that is closed for the weekend; the elimination of redundant work and unnecessary tasks such as retyping and laborious manual filing and retrieval; better utilization of human resources for tasks that require judgment, initiative and rapid communication; faster, better decision making that takes into account multiple, complex factors, and full exploitation of the virtual office through expansion of the workplace in space and time.

MAILMOBILE, a driverless battery-powered delivery vehicle made by Bell & Howell, mechanizes intraoffice deliveries. Here it is negotiating a curve as it makes its way through the research department of Merrill Lynch and Company. The vehicle follows a chemical pathway, which is easily applied and modified to trace any route from the mail room through the office and back to the mail room. An emitter of ultraviolet radiation under the vehicle makes the chemical fluoresce; an optical sensor detects the fluorescent path. The Mailmobile moves at about one and a half feet per second (one mile per hour), beeping and flashing blue headlights. It stops at pickup and delivery sites designated by a coded pattern in the chemical pathway. Bumpers stop the vehicle on contact with a person or another obstacle. An "intelligent" version is being introduced that can be directed to choose among alternate paths or to board an elevator.

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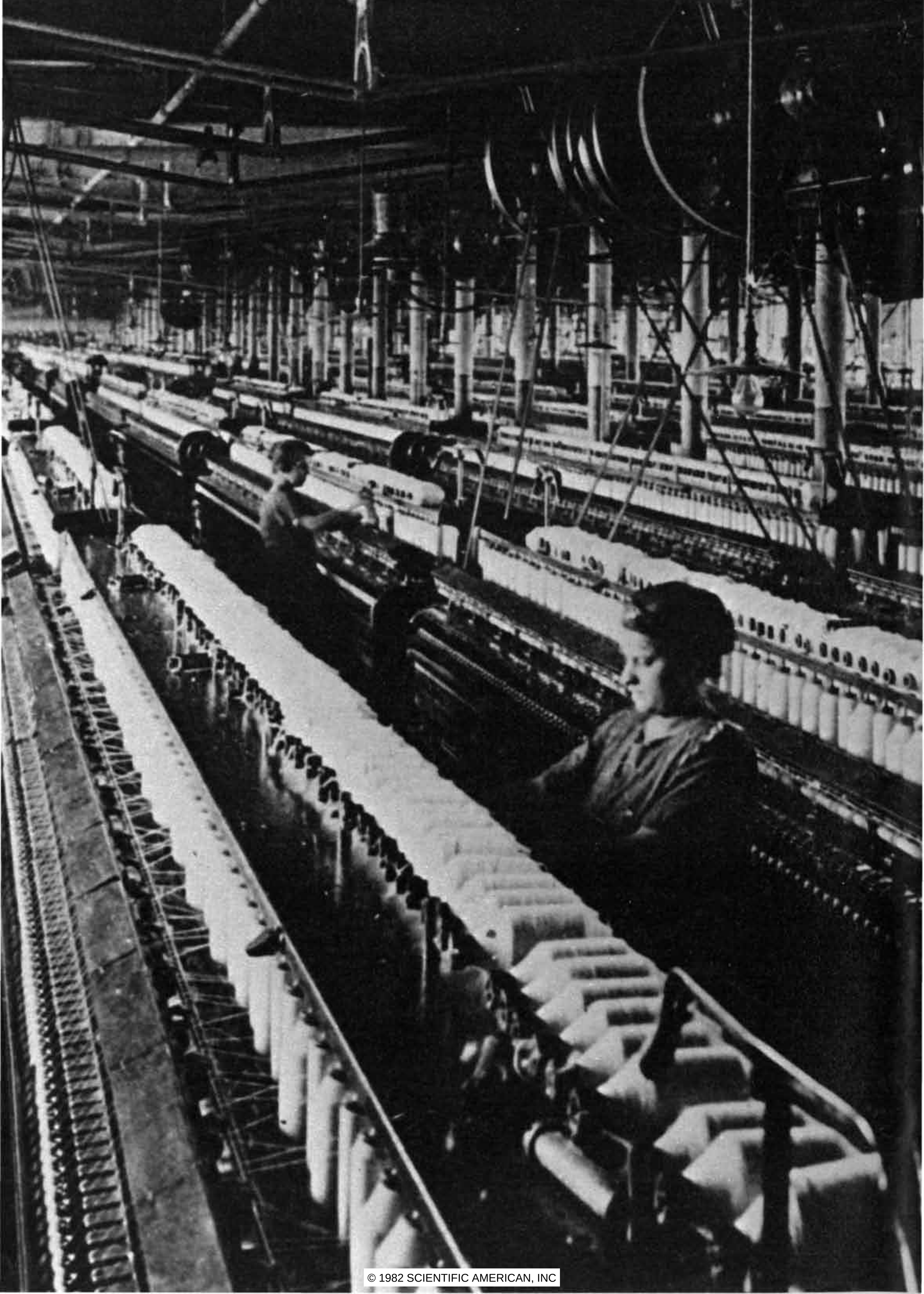


The Mechanization of Women's Work

When it began two centuries ago, it was characterized by low pay and occupational segregation. The same holds true today, although women are entering the labor force in larger numbers

by Joan Wallach Scott

It is frequently assumed that the mechanization of work has a revolutionary effect on the lives of the people who operate the new machines and on the society into which the machines have been introduced. For example, it has been suggested that the employment of women in industry took them out of the household, their traditional sphere, and fundamentally altered their position in society. Both advocates and critics of mechanization have shared the assumption. As women began to enter factories in increasing numbers in the 19th century Jules Simon, a French politician, warned that "a woman who becomes a worker is no longer a woman." Friedrich Engels, on the other hand, thought women would be liberated from the "social, legal and economic subordination" of the family by technological developments that made possible the recruitment of "the whole female sex... into public industry." Thus two observers could have diametrically opposed views on the value of mechanization for women without either one doubting that mechanization would transform women's lives.

Simon and Engels and many others imputed such transforming power to technology partly because they thought the capacity of mechanization to alter human relations was inherent in the machines themselves and hence capable of powerfully affecting the social context in which the machinery was utilized. This hypothesis has now been seriously questioned by historians, particularly those investigating the history of women. Scholars who have examined the experience of women in industrial society have concluded that such innovations as the spinning jenny, the sewing machine, the typewriter, the telephone, the vacuum cleaner and the computer have not fundamentally changed the economic position of women or the prevailing evaluation of women's work. Dramatic technological changes did not result in equally dramatic social changes. For example, the employment of young women in early textile mills was often an extension of an older pattern of employment of young single women. The employment of women in offices was the result of the separation of secretarial work from administrative work and the consequent creation of a class of jobs with little opportunity for advancement; the new jobs were often thought to constitute "women's work." The increased employment of married women in the 20th century, which was a substantial social change, had less to do with mechanization than it did with other economic and demographic trends.

It is undeniable that some aspects of women's work have changed considerably in the past 200 years. Work has moved from the household to the office or factory; in many cases it has become white-collar work rather than blue-collar work. In certain essential respects, however, the work that women do has changed little since before the Industrial Revolution. Occupations are still frequently segregated according to sex. Women as a group are paid less than men. Their work in many cases calls for a relatively low level of skill and offers little opportunity for advancement. For women with families household labor remains demanding, even if they can afford household appliances their grandmothers would have found miraculous. A decade of historical investigation has led to a major revision of the notion that technology is inherently revolutionary, at least as the notion applies to women. The available evidence suggests that on the contrary mechanization has served to reinforce the traditional position of women both in the labor market and in the home.

Mechanization has, of course, had a revolutionary effect on the processes by which goods are made and the organization of the workers who make them. Steam-driven spinning and weaving machines introduced in the 19th century could make in minutes as much thread or cloth as hundreds of individual artisans had been able to make in days or weeks. The new machines simplified the tasks required to make finished goods, divided the work into small, repeated operations and brought together under one roof large numbers of people doing similar work.

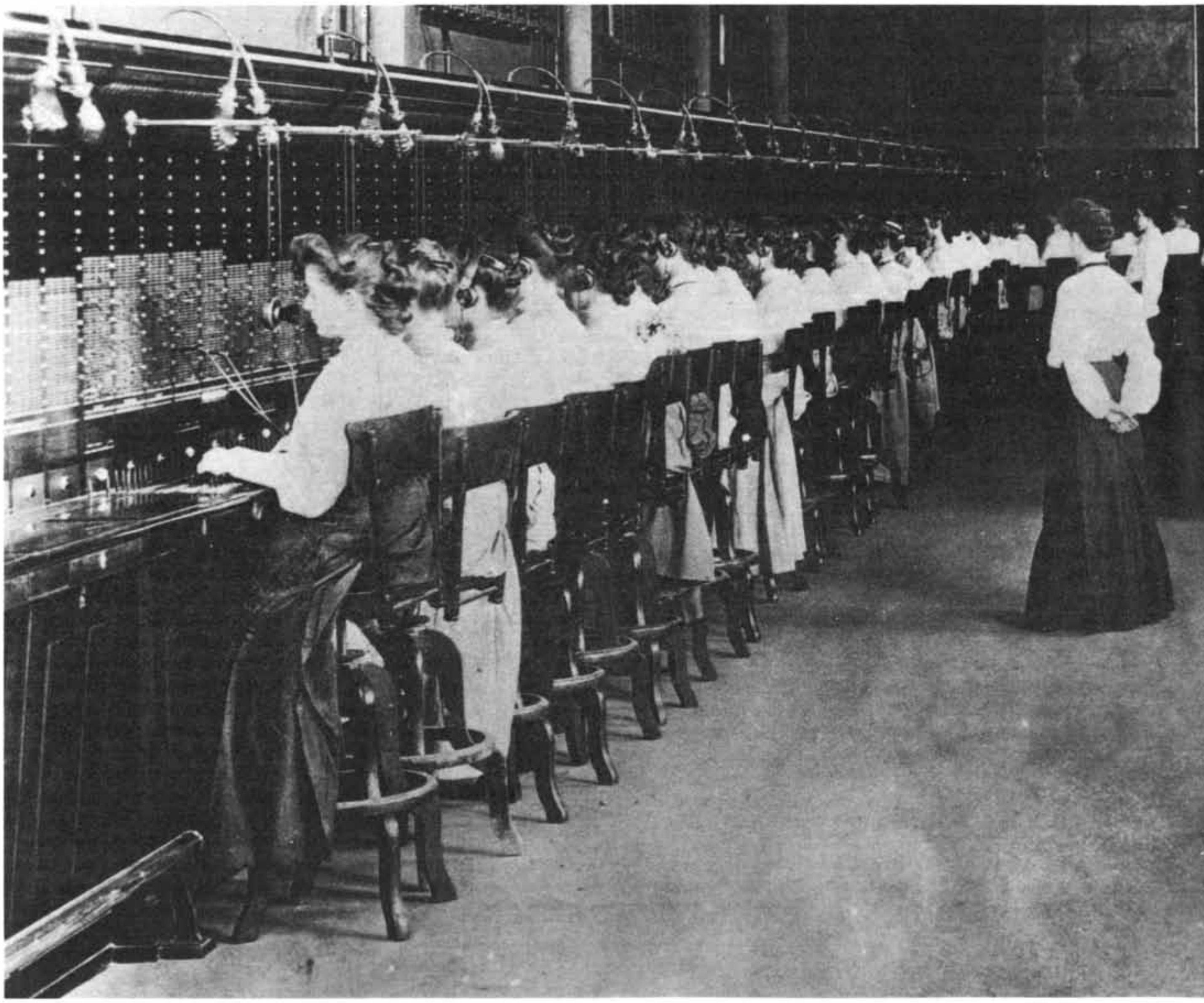
Many of those who went to work in the new mills in Europe and the U.S. were young women who had left farms and spinning wheels to take jobs as machine operatives. The contrast between the experience of the farm girl and that of the mill worker was dramatic, and it could be overwhelming. The contrast is evident in a thinly fictionalized account written by a woman who had been a new arrival at a textile mill in Lowell, Mass.,

SPINNING YARN, traditionally done by women at home, moved into factories as the result of the mechanization of the textile industry. The photograph on the opposite page shows the spinning room of Pacific Mills in Lawrence, Mass., in 1915. Spinning is the drawing out and twisting of cotton fibers to form yarn. It was originally done by hand with the distaff and the spindle. The first mechanical advance was the invention of the spinning wheel in the Middle Ages. Before the establishment of textile mills most spinning was done at home with spinning wheels. The development of power looms made it impossible for women to supply enough yarn by this means. To increase the supply several innovations were combined in the late 18th century in England to yield large water- or steam-driven spinning machines. The ring-spinning machines shown in the photograph were the commonest type of spinning frame in the U.S. in the early 20th century. All the machines in the spinning room were driven by a single electric motor; power was transmitted to the machines by the belts extending from the ceiling. The upright bobbins at the top of the machine held the crude ropelike material called roving. The strand of roving was drawn down between two leather-covered cylinders and through a loop of wire called the traveler. The traveler moved on a ring circling the yarn bobbin. The yarn bobbins are at waist level; each machine had about 300. The traveler revolved about the bobbin some 10,000 times per minute, stretching and twisting the yarn as the ring moved up and down distributing the yarn evenly. In the early mills most of the women who operated spinning and weaving machines came from farm or artisan families. Such women had customarily worked before marriage; the opening of the mills merely changed their place of employment.

in the 1830's: "At first the sight of so many bands, and wheels, and springs in constant motion was very frightful. She felt afraid to touch the loom, and she was almost sure that she could never learn to weave.... The shuttle flew out and made a new bump upon her head; and the first time she tried to spring the lathe, she broke out a quarter of the threads."

Industries other than textiles also began to draw workers from the pool of young single women, including the manufacturers of paper, buttons, shoes and watches. Later in the century the makers of electric wire and light bulbs recruited labor from the same source. Images of the factories where such goods were made capture the novelty of the workers' experience. In engravings and photographs rows of young women stand at attention before their machines. The depiction of many employees with identical posture, dresses and hair styles conveys the scale of the enterprise. The images give female labor a uniform and impersonal quality that was then strange. The comparison implied in such images is with the more intimate surroundings of the household.

Those who argue that the new techniques of manufacturing had a revolutionary impact on women assume that factory work drew women permanently from their traditional place in the home. Implicit in the argument is the notion that women did not work for wages or engage in other productive activities before the Industrial Revolution. The opportunity to earn wages, it is thought, gave women entry into the world of men, where they found independence and social recognition. In reality women's work in the early factories was conceived by employers (and to some extent by the women themselves) in traditional terms. The most important of these was that wage work was a secondary occu-



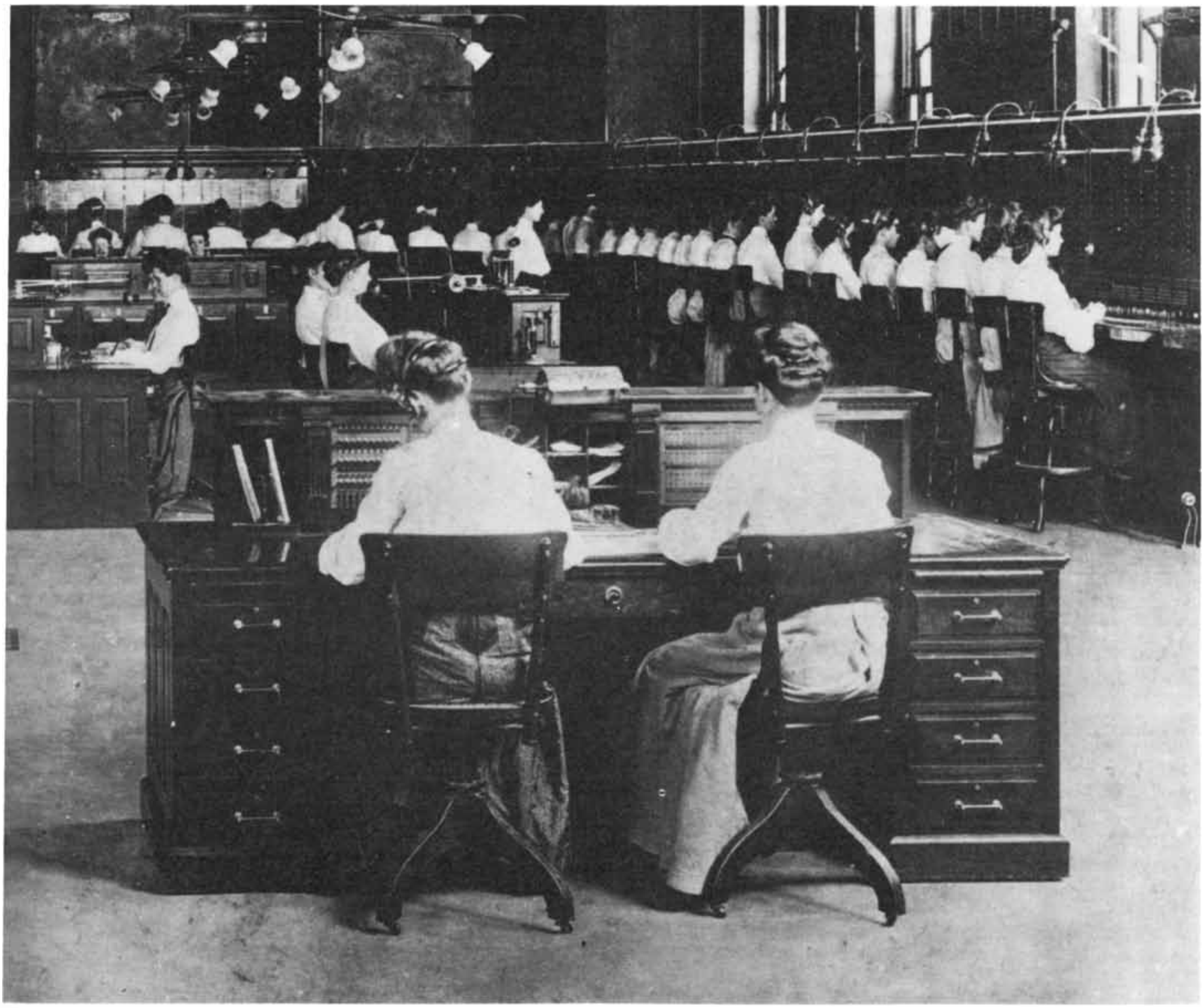
TELEPHONE EXCHANGE was a place of employment for increasing numbers of young women in the early part of the 20th century, as is indicated by this photograph of the central exchange of Kansas City, Mo., in 1904. The switchboard shown is of the type called a multiple switchboard. Introduced in 1897, it incorporated numerous advances over its predecessors. The first switchboards were cumbersome: the signaling operations (such as the customer's indicating to the operator that he wanted to make a call) were handled by equipment separate from that utilized for calling. All the circuits were incorporated in a single board. Much of the subsequent improvement resulted from the invention of the switchboard jack, a small socket that carried current for both signaling and calling. The call was put through by connecting two jacks with a short cord that had a plug at each end. A version of the jack was patented in 1879. By 1897 the jack had been made small enough so that 10,000 lines could be put within the reach of one operator. A further advance was to separate the jacks of callers ("answering jacks") from those of the people to be called ("connecting jacks"). Each operator had in front of her on three

pation and that a woman's real work was raising children and running the household. The traditional conception was demonstrated in the employers' preference for hiring women who were young and unmarried: most machine operatives were between the ages of 16 and 25.

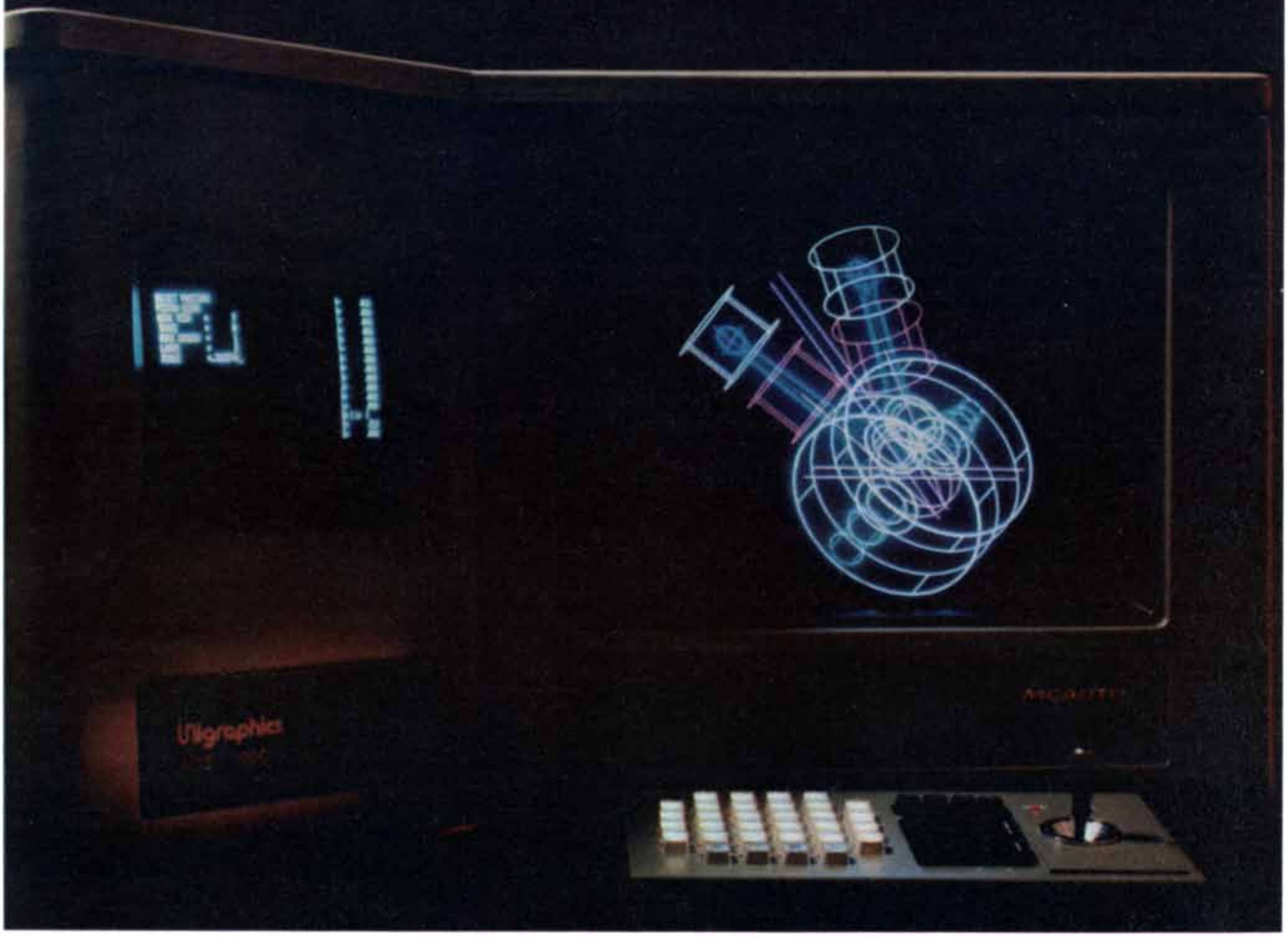
That factory work was an extension of previous experience is further demonstrated by the fact that the operatives came largely from artisan and agricultural families; such families had for generations expected their daughters to work at home, in a cottage industry or in domestic service until they married. In both Europe and the U.S. there was substantial variation among regions and social groups in the fraction of young single women who earned wages. In spite of the variation the fact remains that in Europe and the U.S. many young women worked outside the home. When the mills opened, they offered better pay and more jobs than had previously been available to young women, who merely shifted their employment to a new place.

Furthermore, a job in the mill did not alter the anticipated course of a woman's life by substituting paid employment for marriage and the care of children. Mill work simply provided young women with a new kind of job at a time of life when they would ordinarily expect to be employed. Most operatives took jobs for immediate financial gain and not in the hope of a career. Once a woman was married, unless her family desperately needed her wages there was little reason for her to spend her adult life as a mill worker. The possibility of promotion and higher pay was remote. The majority of women therefore left the mill when they married or when they later had children.

The work force in the mill therefore



vertical panels connecting jacks for every subscriber in the system. On a horizontal shelf she had answering jacks for only a fraction of the subscribers. To place a call the customer lifted the receiver, activating a circuit that lighted a lamp above the answering jack. The operator inserted one plug in the answering jack; the lamp went out and power for voice transmission was supplied from a battery in the telephone-company building. The operator pressed a key, thereby connecting her headset to the circuit, and asked for the number to be called. If the desired line was free, she put the other plug into the connecting jack and pressed a key that rang the telephone bell of the person being called. Lights on the switchboard indicated when the call was answered and when either person hung up. The first commercial telephone exchange was established in New Haven, Conn., in 1878 with 21 subscribers. In the earliest exchanges the operators were young men, but women replaced them in the 1880's. Work as a telephone operator was clean and respectable and therefore thought to be suitable for the young single middle-class women who were beginning to work in substantial numbers in the late 19th century.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consisted largely of single women, with a minority of poor married women and widows. The turnover in the work force was high, but employers did not object because the turnover did not hamper production. Women learned their tasks quickly, and they accepted the conditions in the factory, in part because they did not expect to stay there. From the point of view of the mill owner whatever drawbacks there may have been in a constantly changing female labor force were outweighed by one great benefit: such a labor force was cheap.

One keen observer of the process of industrialization in England was a Scottish professor, Andrew Ure. Like many of his contemporaries he was fascinated by the emerging industrial processes; he traveled through England recording his observations of factories. In 1835 he noted: "It is in fact the constant aim and tendency of every improvement in machinery to supersede human labour altogether or to diminish its cost, by substituting the industry of women and children for that of men.... In most of the water-twist or throstle cotton-mills [a throstle was a large spinning frame driven by water power], the spinning is entirely managed by females of 16 years and upwards. The effect of substituting the self-acting mule for the common mule is to discharge the greater part of men spinners and to retain adolescents and children. The proprietor of a factory near Stockport states that by such substitution, he would save £50 a week in wages, in consequence of dispensing with nearly forty male spinners at about 25*s* of wages each."

Ure's observation reflects the longstanding belief that women did not merit or require wages as high as those of men. Because of exclusion from trades practiced by men, a lack of training and the assumption that women's wages would supplement the family income rather than provide it, the prevailing evaluation of women's work was that it was worth less than that of men.

Not only were women in the mill paid less than men for the same work; cultural attitudes about women's capacities also led to the designation of many jobs as being suitable primarily for women. Employers hired women as mill operatives, they said, because their small, graceful fingers could piece the threads together easily. In addition the female temperament—passive, patient and careful—was thought to be perfectly suited to boring, repetitive work. Men were employed in the mills as supervisors, mechanics and occasionally as operatives in such tasks as carding, which required considerable strength. Women tended spinning, winding, warping and weaving machines. The specific jobs done by men and women varied from mill to mill, but the separation of male and female work was almost universal; in most mills many rooms were staffed entirely by women. Thus the pattern of

CLERICAL WORK was transformed between 1880 and 1910, in part by the introduction of the typewriter. This photograph depicts part of the Audit and Policy Division of the Metropolitan Life Insurance Company in about 1910. It reveals one of the results of the transformation: women had replaced men as clerical workers. In the Audit and Policy Division the reports of field agents were audited and insurance policies were written. In 1910 the division had more than 500 women clerks who worked at the typewriter, which had become a practical instrument of office work. The first workable typewriter was made in 1867 by Christopher Latham Sholes. Sholes's machine was put on the market in 1873 by E. Remington & Sons, the gunsmiths, as the Remington No. 1. It had many of the features of the modern manual typewriter, including a cylinder with line-spacing and carriage-return mechanisms, an escapement for the spacing of letters, and type bars that struck at a common point on the cylinder. The keys were in an arrangement much like that of the modern machine. Two further advances were required to yield the typewriter of 1910. One was the shift key, which made it possible to type both capital and lowercase letters on a single keyboard. (The Remington No. 1 could type only capital letters; some contemporaneous designs had a second keyboard for the lowercase letters.) The other advance was the placement of the paper so that the work could be read while it was being done. (In most of the early machines the type bars had struck at a point on the underside of the cylinder and the carriage had to be lifted for the work to be read.) In 1910 women were relatively new participants in clerical work. Earlier, young men had done such work in preparation for administrative positions. The growing volume of paperwork in the 1880's and 1890's resulted in the creation of large numbers of secretarial jobs with little opportunity for advancement. Because the new jobs did not offer the possibility of a career they were thought by employers to be suitable for women. The segregation of women in such work is indicated by the fact that in 1908 the Audit and Policy Division had 287 bookkeepers, all of whom were men, and 752 clerks, all of whom were women.

separate realms of work for men and women remained undisturbed. (The notion of separate spheres of work for men and women is so deeply entrenched in cultural images that the division is presumed to extend to the first workplace, where "Adam delved and Eve span.")

Wages for women lower than those of men and the segregation of jobs according to sex were often the result of mechanization in the 19th century and the early 20th. Machinery that extended the division of labor, simplified and routinized tasks and called for unskilled workers rather than skilled craftsmen was usually associated with the employment of women. From the point of view of the skilled workers displaced by machinery feminization meant the devaluation of their work.

The increase in female white-collar office work at the end of the 19th century was a new variation on the theme. The telephone and the typewriter have come to symbolize the reorganization of clerical work at that time. These innovations, however, were only a small part of the reorganization. Increases in the urban population and manufacturing and the consequent expansion of commerce called for enormous amounts of paperwork. Earlier in the 19th century young men had done clerical work as part of a general apprenticeship in business; such apprenticeships were often preparation for partnership or inheritance of the enterprise. As the volume of paperwork increased, however, clerical work was separated from administrative work and from advancement in the executive hierarchy.

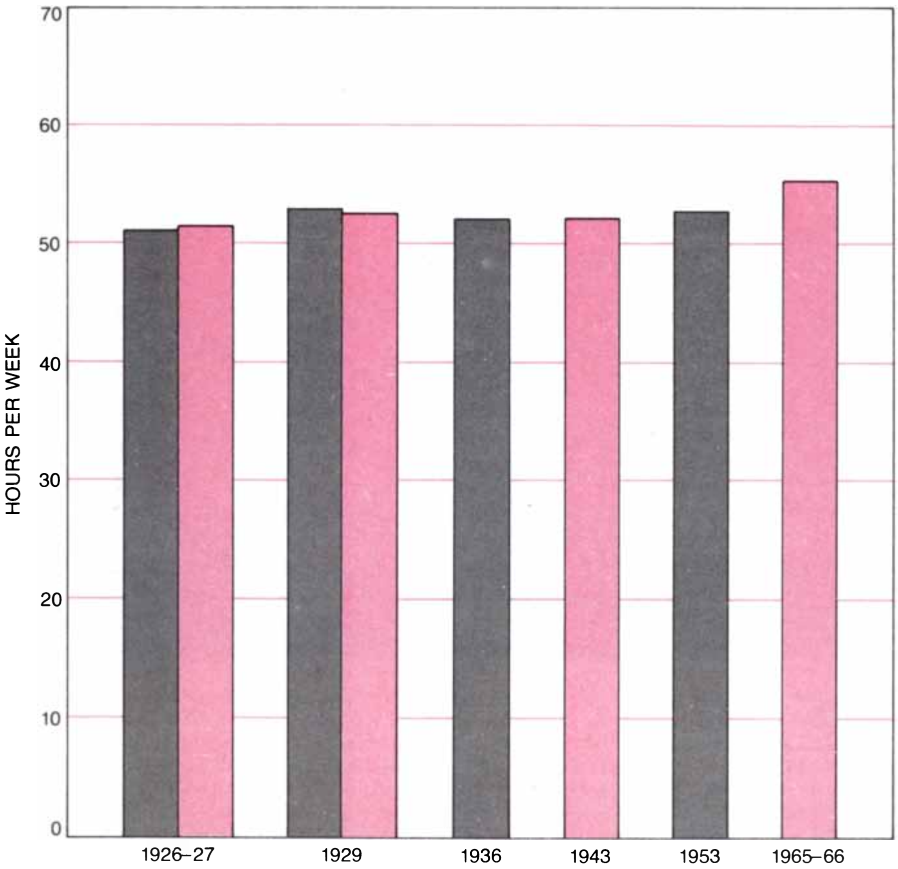
In the early phase of the development of the modern office, copy work was given out to women to be done at home. In the U.S. such workers were usually married women or widows with children who supplemented the household income by copying; they were paid by the word. The literacy of the copy workers indicates that they were educated women and therefore probably from artisan or even middle-class families.

The first phase of modern office work did not last long. The first practical typewriter, invented in 1867, was introduced into commercial use in the 1870's and quickly became standard office equipment. Typing, stenography and filing became components of a full-time job done in the office. As the role of secretary was created ambitious young men moved into sales, advertising and administrative positions. Women were hired in the new white-collar service jobs. The shift took only a few decades. In the U.S. census of 1880 only a few women were listed as office clerical workers. By 1910, 83 percent of all stenographers and typists were women; the proportion was similar in France and England. The feminization of clerical work has continued: in 1980, 97 percent of typists in the U.S. were women, as were 89 percent of stenographers.

Hence like the spinning and weaving rooms of the textile mill the outer office quickly became a feminine space. Office work, however, had qualities that distinguished it from blue-collar work. It called for some formal education. Furthermore, because it was clean, respectable work it was thought to be suitable for middle-class women who had not previously worked for wages. Families who wanted relief from supporting a single daughter or who sought to give marketable skills to daughters who might not marry or whose husbands might die young sent their daughters to commercial schools and then into the job market. In the 1870's such economic and demographic pressures had propelled young middle-class women into nursing and teaching. In the 1890's and 1900's the pressures moved them toward the newly available office jobs. In the offices they were joined by women from poor families who had gone to commercial training schools to acquire the skills for a white-collar job.

The secretary (once widely known as the "female typewriter") and the telephone operator quickly replaced the machine operative as the typical female worker. Their work was much less dirty and less difficult than mill work. There were, however, fundamental similarities between the situation of the blue-collar workers and the white-collar ones. The mechanization of document copying and communications created new occupations while maintaining women in a labor market separate from that of men. Occupations were still segregated according to sex, and the cultural stereotypes of women's capacities were closely associated with the work. It was said that women's fingers raced as deftly over the typewriter keys as if they had been playing the piano. According to employers, women's ability to greet strangers pleasantly, their reliability and their tolerance for repetition made them ideal telephone operators.

Just as jobs in the mill had been, so the jobs of secretary and telephone operator were designated as employment for single women. Age limits of between 18 and 25 were usually enforced. Em-



TIME SPENT IN HOUSEWORK each week by women not employed outside the home changed little between 1926 and 1966. Gray bars are for rural women, colored bars are for urban women. The data are from various comparable surveys. The period was one in which the urban population grew and the ownership of household appliances became widespread. It has been argued that such appliances freed women to do other kinds of work. By the late 1960's, however, women not employed outside the home still spent more than 50 hours per week in housework. Women who were employed also spent a substantial amount of time in housework: 26 hours per week. It appears that rather than being freed for other kinds of work by household appliances many women went to work largely in order to be able to buy such appliances.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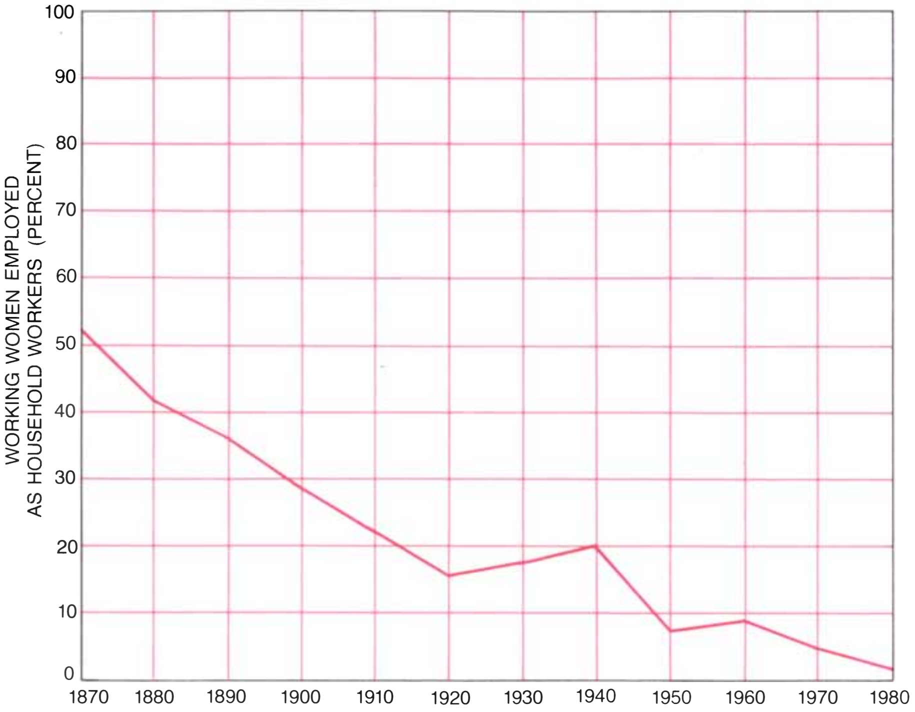
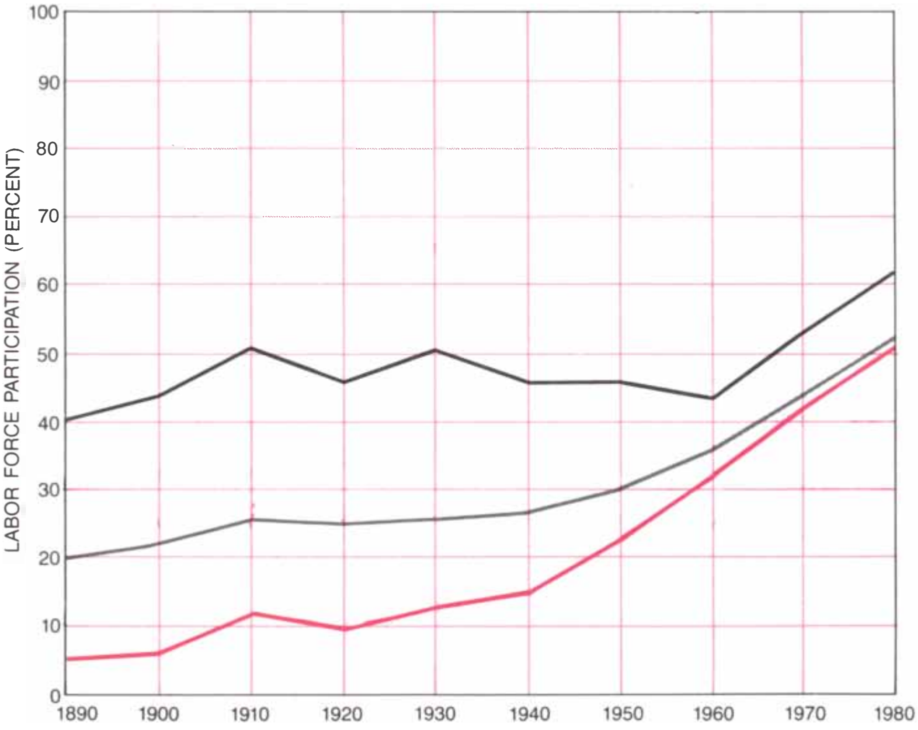


HOUSEHOLD WORKERS (other than family members) represent a diminishing fraction of all working women. In 1870 more than half of all employed women were household workers; by 1980 the fraction had decreased to about 2 percent. The reduction in the availability of domestic servants, along with higher standards of household cleanliness and the presence of laborsaving appliances, has served to increase housework for middle-class women. With the aid of appliances such women now spend much time doing work that was once done by servants.



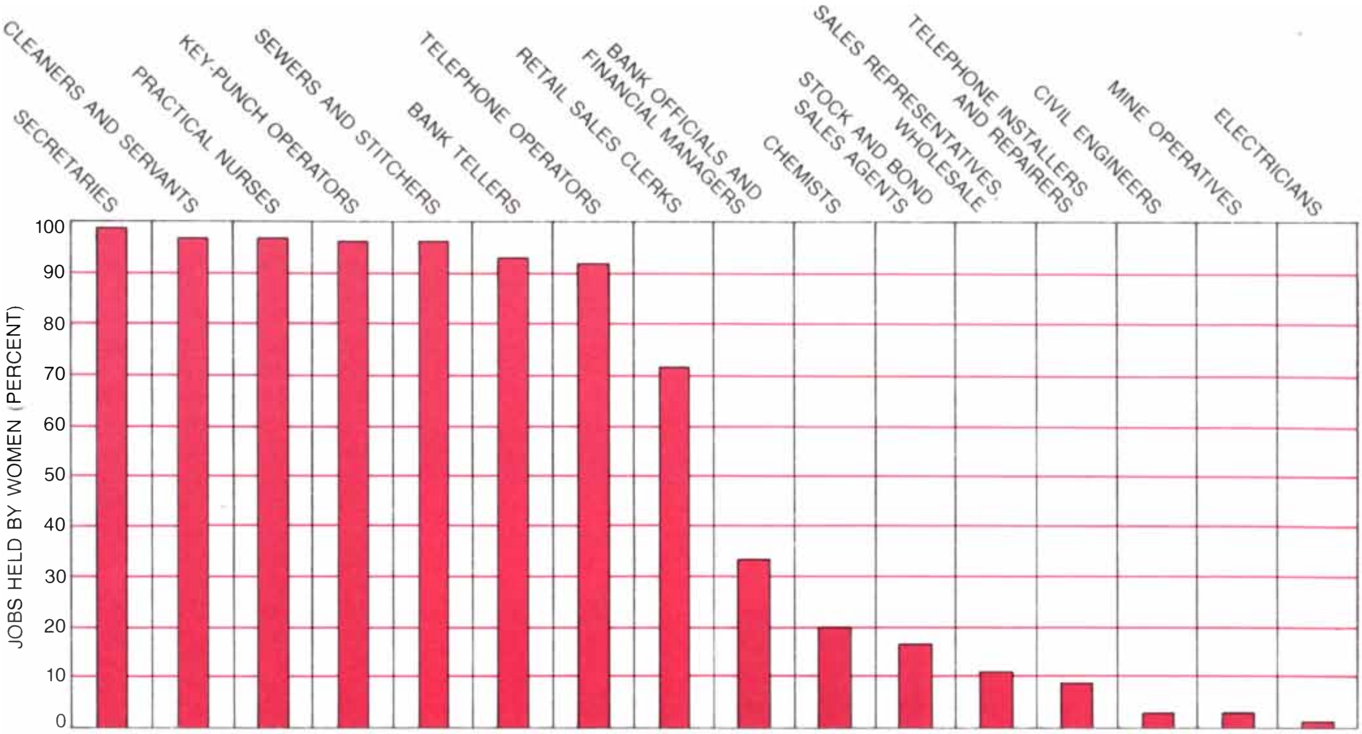
FRACTION OF MARRIED WOMEN WHO WORK has increased greatly since 1900. The black line shows the labor-force participation rate for single women, the gray line the rate for all women, the colored line the rate for married women. About half of all married women now work outside the home, compared with about 5 percent in 1900. In the 19th century and the early 20th most working women were single. Work did not change a woman's anticipated life course, because women stopped working when they married. The increase in the employment of married women was a substantial social change, but it appears to have had little directly to do with mechanization. One interpretation is that married women became acceptable employees only when the pool of single women did not expand rapidly enough to meet labor needs.

ployers often required young women to leave their job when they married whether they wanted to leave or not. A businesswoman who ran a commercial training school for female office workers early in the 20th century explained the difference between the careers and wages of men and those of women as follows: "Women must admit to one handicap in an independent business life—business wears a temporary aspect to most girls. For if she is normally constituted, every girl hopes that someday she will be happily married."

The temporary nature of employment made promotion and an institutionalized career path unnecessary; because women in business were not promoted regularly their wages remained low and stable. In addition employers assumed, although it was not always true, that young women did not have families to support and indeed that they were supported by their families. As a result the wages of female clerical workers were generally about half what male clerical workers had earned. For this reason men denounced the invasion of the office by women. A male former clerk wrote that "women are employed not on account of their capacity but because they are cheaper than men."

In spite of a substantial change in the composition of the female labor force working women are still paid less than their male counterparts. Since World War II there has been a dramatic increase in the proportion of married women who work; the increase has been particularly marked among those with young children. The increase has had little to do with mechanization, including, as I shall show, the mechanization of the household. No major technological innovation appears to have been directly associated with the increase in the number of married women who earn wages. Rather than being the result of mechanization the increase has been caused by a series of economic and demographic developments that have drawn married women into the kinds of jobs once held by single women.

Valerie Kincaid Oppenheimer of the University of California at Los Angeles has argued that married women became acceptable employees when the pool of single women workers decreased as a result of extended education and higher marriage rates. Over the same period inflation and the desire to maintain an increasingly high standard of living led many married women to seek work outside the home. Their motives, like those of the married women who worked in the early textile mills, were economic. For many 20th-century women, however, the immediate aim was not to secure food for the family but to pay off a mortgage, send children to college or buy laborsaving appliances. In the late



SEGREGATION OF OCCUPATIONS BY SEX has not been eliminated by the mechanization of work. This chart shows the fraction of workers in selected occupations who are women. The data are for 1980; they are from the U.S. Department of Labor. The occupations dominated by women are for the most part unskilled and poorly paid. Those dominated by men are a mixture of well-paid skilled jobs and blue-collar jobs. There are sharp distinctions between women's work and men's work even within a particular industry or between closely related occupations. In such cases men dominate the better-paid occupations. For example, the occupation of telephone operator, which became women's work in the 1880's as a result of mechanization and other factors, has remained women's work: in 1980 more than 90 percent of operators were women. Telephone installers and repairers, however, were overwhelmingly male. In 1980 more than 70 percent of retail sales clerks were women. Most wholesale salesmen, however, were men; only about 10 percent were women.

1970's and early 1980's, as the inflation rate and the divorce rate have increased, the older subsistence motive has reappeared. Many mothers now work in order to feed and clothe their children rather than to buy luxuries. The extraordinary number of families headed by women that live at or below the poverty level in the U.S. demonstrates that this is so; it also reflects the persistence of the attitude that women's work deserves less pay than men's work.

Although increased employment outside the home by married women was a significant shift, some important qualities of women's work remained unaltered when married women went to work. Manufacturing and white-collar jobs are still segregated by sex. In both kinds of employment men's and women's working areas are often separated spatially. Thus in modern workplaces there are not only men's and women's jobs but also men's and women's spaces, in the same sense in which the early telephone exchange was a women's space.

Observation of the effect on marriages and on children of women's leaving home to work has led some economists and employers to argue that if wage work is necessary, it ought to be done in a married woman's traditional space: the home. In the case of office work, which now employs the largest proportion of working women, electronic equipment could make it possible for married women to work at home [see "The Mechanization of Office Work," by Vincent E. Giuliano, page 148]. Connected by telephone lines to administrative headquarters, workers could operate word processors, retrieve and store information and do various other clerical and secretarial tasks. Mechanization might thereby reconcile work and child care for many women. It could also make it unnecessary for social planners to consider whether the nuclear family is the best form of organization of biological reproduction and child care.

It seems unlikely, however, that computer technology will transform the enduring characteristics of women's work. On the contrary, computer terminals in the home would probably lower secretarial wages. The reason is that the machines themselves make it possible to do large amounts of work quickly and therefore reduce the number of workers needed to do a given amount of work. The resulting increase in competition for jobs would drive wages down. Moreover, it is probable that when home terminals become common, employers will substitute piece rates for hourly wages or salaries. Piece rates offer a more efficient means of controlling unsupervised work than payment according to time worked. The isolation of office workers in the home would make it difficult for them to discuss shared grievances, as workers now can in the workplace, and hence would make it difficult for them to organize collectively. As a result it would be possible for employers to pay low and unequal wages.

By enabling married women to work at home for wages computers might have an effect on women analogous to that of the sewing machine in the 19th century. Sewing machines made needlework much more efficient. Initially, however, the machines were installed in the workshops of clothing manufacturers or subcontractors. In the 1890's the manufacture of lighter and cheaper models made sewing machines practical for home use. Along with the purchase of a sewing machine often went wage work at home. Advertisements for sewing machines sometimes included a contract with a garment manufacturer as an inducement to buy. If a woman signed a contract, she could by doing piecework both pay for her sewing machine and earn additional money.

Work at home was not a new occupation for married women. Women of the urban working class in Europe and the U.S. had long helped to support their family by means of such work. In some instances full-time entrepreneurial work overlapped the home, as in the case of women who were innkeepers;

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other women did metal polishing and laundry in the home; still others did piecework such as making hats or artificial flowers or spinning silk.

The commonest occupation for married women at home, however, was sewing. The practice of earning wages by sewing at home became more widespread with the growth of the ready-made clothing industry. In the best circumstances married women combined sewing with child care and housework. Their earnings supplemented those of a husband and in some cases working children. The fact that the money earned in this way was supplemental to the family income enabled the women to exercise some control over the rhythm of their work. Sewing for a few hours a day was profitable employment while the children were at school.

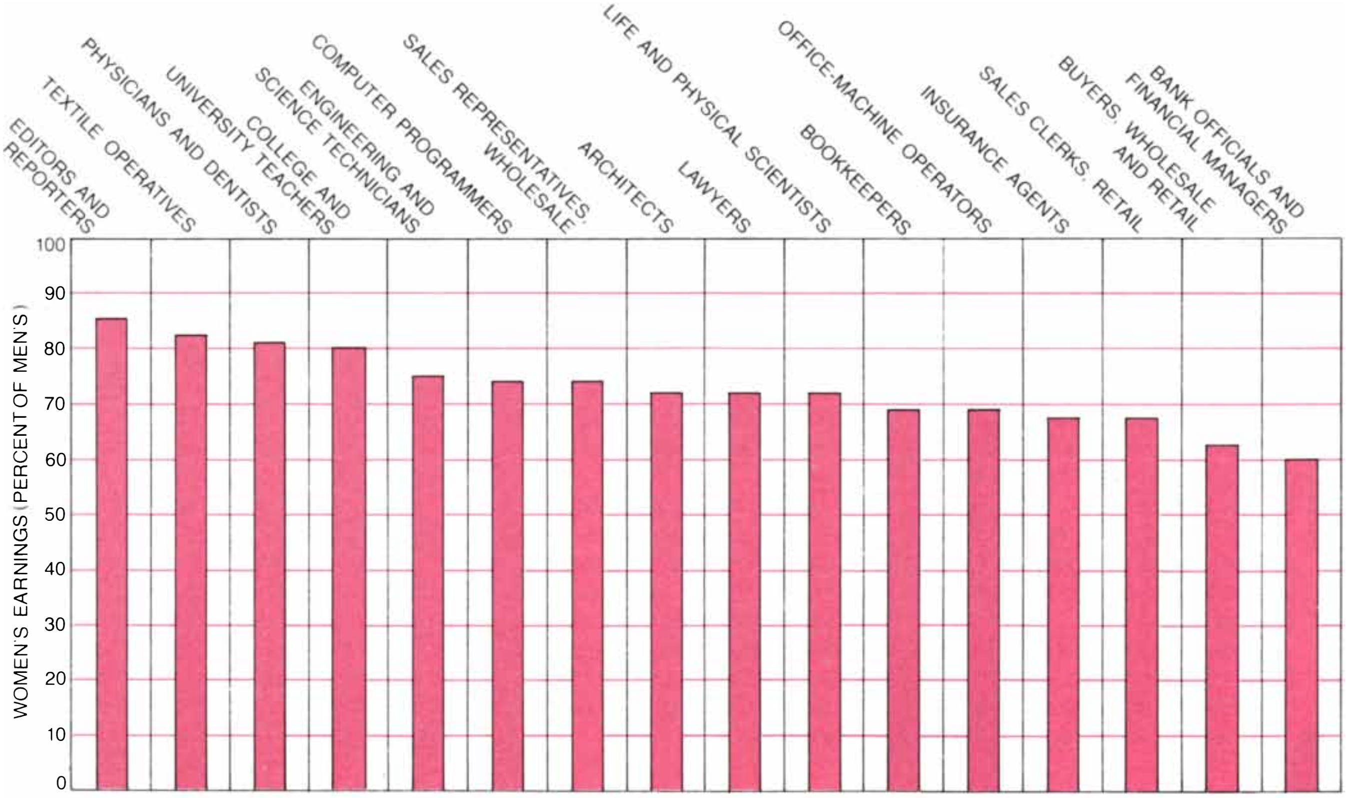
Such relatively fortunate women were in the minority; most women sewed because they needed as much money as they could possibly earn. Because employers paid by the piece and the rates were low, long hours were needed to earn even a subsistence wage. Some working-class women spent every waking moment sewing and required the labor of as many family members as were available. It was common for children to be kept home from school so that more garments could be sewn. The sewing machine transformed such households into miniature sweatshops. The mother ran the machine while children and relatives sewed hems and put on buttons. Neighbor women who could not afford their own machines sometimes joined the work force, bringing young children to sleep or play while they worked. Social reformers at the turn of the century described tenement rooms filled with women and children whose voices could barely be heard over the noise of the sewing machine. The reformers deplored the low piece rates that led women to work 15 or more hours per day, neglecting their children and household.

The sewing machine increased the speed with which goods could be sewn, standardized the products and perhaps created more jobs. The machine did not, however, alter the low rate of pay, the fact that most home workers were women and the fact that most married working women worked at home. Thus the mechanization of needlework did not free working-class women from the household; instead the sewing machine was incorporated into the traditional pattern of work at home.

The sewing machine had a different effect on women who did not use it as a means of earning money. Housewives who had previously bought clothing ready-made began to make clothes at home with the aid of the patterns that were printed on the women's pages of newspapers and magazines and sold in fabric stores. The practice of making the family's clothes had diminished in importance with the introduction of mass-produced garments. By encouraging women to return to the older practice the mechanization of sewing reduced the time a housewife spent as a consumer and increased the time she spent as a household worker.

The sewing machine was one of several devices that "industrialized" the middle-class household in the first decades of this century. The washing machine, the iron and the home freezer also reduced the urban housewife's reliance on services provided outside the home. The new appliances individualized the preparation and preservation of food and the making and maintenance of clothing and linen. Instead of buying services, the housewife did the job herself with the aid of her appliances. The vacuum cleaner and the dishwasher had a similar effect, but those appliances did work that had been done by servants in most middle-class homes.

Some observers of mechanization have suggested that there is a causal relation between the industrialization of the household and the entry of married women into the labor market. It is usually argued that household appliances so diminished the time housewives needed for domestic chores that they had time for paid work outside the home. John D.



WOMEN'S EARNINGS are less than those of men in the same occupation in almost every field. The bars indicate women's earnings as a fraction of men's. The data are for 1981; they are from the U.S. Department of Labor. The differential between the earnings of men and the earnings of women varies from about 40 percent among bank officials to about 15 percent among editors and reporters. The differential exists in both skilled and unskilled occupations; it exists in occupations dominated by men and those dominated by women.

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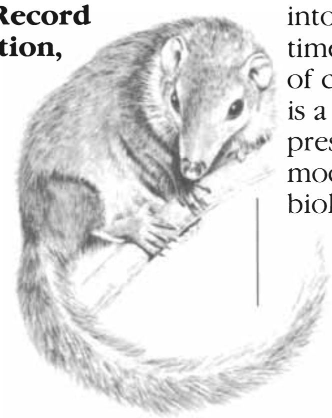

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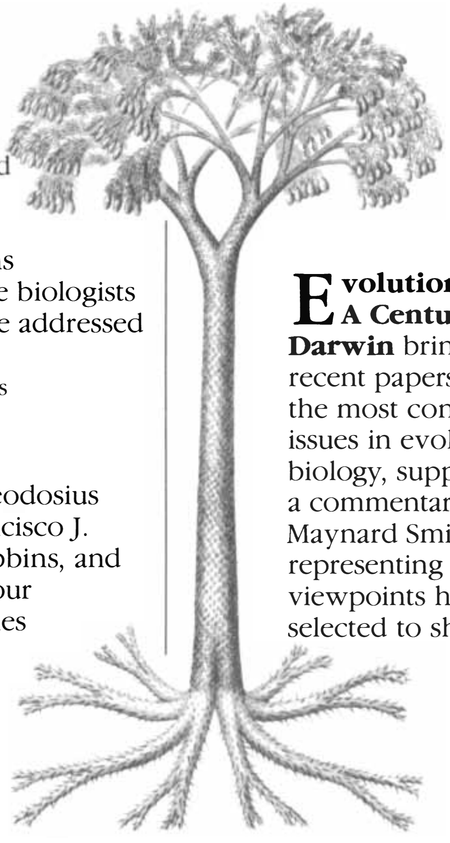

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Durand of the Bureau of Social Affairs of the United Nations predicted in 1946 that laborsaving household appliances might "virtually... eliminate the home as a place of work and housewives as a functional group in the population." The work of Joann Vanek of the UN Statistical Office, however, shows that between 1920 and 1960 the time women not employed outside the home spent in housework increased [see "Time Spent in Housework," by Joann Vanek; SCIENTIFIC AMERICAN, November, 1974]. The four decades covered by Vanek's study constitute a period when the urban population of the U.S. increased and the ownership of household appliances spread throughout the population. In spite of the fact that rural women preserved food and did much more physical work than urban women, Vanek's investigation shows that urban housewives spent more time in housework than rural ones.

One reason for the increase in the time spent in housework appears to have been the decrease in the proportion of urban families that had domestic servants. By the 1920's the population of servants had declined both in number and as a proportion of the female work force. In 1870, 52 percent of employed women were servants; by 1920 the fraction had decreased to 16 percent. Middle-class women without servants found vacuum cleaners and washing machines an attractive investment, but although the appliances eliminated some of the more onerous aspects of housework, they did require someone to operate them. In the household without servants the housewife became the sole domestic worker.

The amount of domestic work was further increased by a rise in the standards of household cleanliness. Ruth Schwartz Cowan of the State University of New York at Stony Brook has shown that this rise accompanied the introduction of household appliances. From the 1890's to the 1920's the home-economics movement portrayed women as scientific managers of the health of the household. Articles in magazines such as *Ladies' Home Journal* emphasized the importance of spotless homes; advertisements in their pages offered soaps and cleaning solutions to help do the job. Even if women spent less time sweeping, scrubbing and rinsing than their mothers and grandmothers had, they did the laundry more often and spent more time waiting in line at stores to buy cleaning agents.

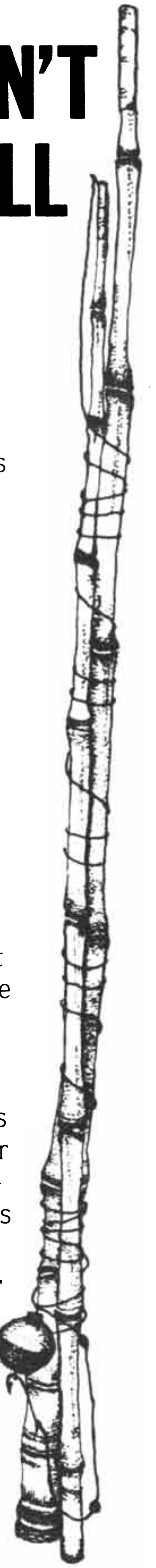
The time spent in domestic chores was also increased by a new emphasis on the principles of child rearing. Mothers were expected to be experts in the psychological, physical and educational development of their children. Household appliances merely enabled women to transfer their attention from one kind of domestic activity to another without by any means escaping such activity altogether. Cowan concludes that "women of the middle class... did not get divorces, nor enter the labor market or the political arena. They were too busy sterilizing bottles, taking children to music and dance classes, making balanced meals, shopping, studying child psychology and sewing color-coordinated curtains."

The hypothesis that laborsaving ma-

CONTEMPORARY TELEPHONE OPERATORS are shown in a photograph made in a Traffic Service Position System (TSPS) facility operated by the New York Telephone Company in New York. Introduced in 1969, the TSPS consists of a base unit where most calls are automatically connected and offices such as this one, where operators handle calls that require human intervention. The TSPS made it possible for customers to dial calls requiring the assistance of an operator, such as credit-card calls. The customer dials the call with the addition of a code indicating that assistance is required. The operator then gets the customer's credit-card number and enters it in the record of the call. The automatic completion of the calling circuit, which eliminated the need for an operator on routine calls, was introduced relatively slowly; by 1925 only about 12 percent of the telephone lines in the Bell System were operated automatically. Thereafter the expansion and mechanization of telephone service were rapid; thus the number of operators increased slowly. In the 1910's the Bell System had 100,000 operators for seven million telephones. In 1970 there were 166,000 operators for 98 million telephones.

THE FISH WON'T BE BITING IN TWITCHELL CREEK TODAY,

OR TOMORROW, EITHER.



There was a time when with a little luck and a little patience, you could pull a fair-sized fish out of Twitchell Creek on Woods Lake in the Adirondacks.

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They've been run off, or killed off by the rain, of all things. A deadly poisonous acid rain which has contaminated the water, choked the life out of the stream . . . and broken the delicate food chain on water and (we're finding out) on land as well.

All rain contains some acid, of course. But acid precipitation is different. And far more dangerous. Acid rain contains two killers: nitric acid and sulfuric acid which form when sulfur dioxide and nitrogen oxide mix with rain water. These two chemicals are being spewed by the ton-load into our air every day . . . emissions from the coal-burning power plants and industrial boilers our nation uses to keep going.

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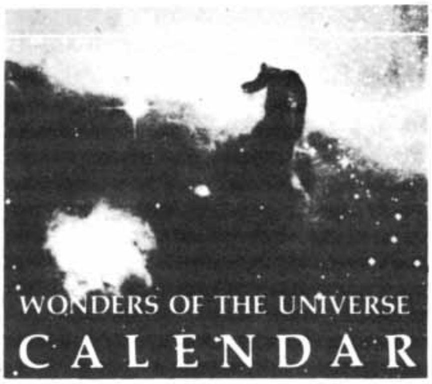
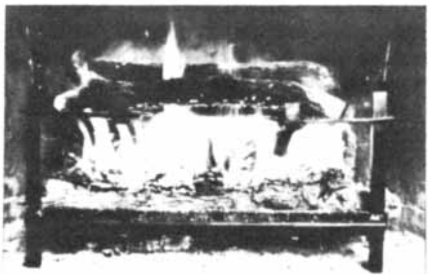




chinery liberated women from domestic work is further weakened by the observation that although middle-class women were the most likely to be able to afford household appliances, they have always been the group least likely to work for pay outside the home. There is little historical correlation between the owning of household machinery and wage earning. In the early part of the century increases in the female labor force were due primarily to single women taking white-collar positions; the increase was due to a lesser extent to poor married women filling less desirable jobs in factories and in domestic service.

The fact that the women who were working were not the ones who owned the new appliances was demonstrated in the stark contrast between the homes of the middle class and those of the working class. Investigators such as Jacob Riis of conditions in the homes of the poor found them lacking in essential comforts and indeed barely furnished. In 1912 an investigator for a Senate committee wrote that "nothing appears comfortable, nothing beautiful." Working-class homes were kept clean by old-fashioned labor-intensive methods. The women of such households were not freed to work by laborsaving appliances; they were forced to work by economic necessity.

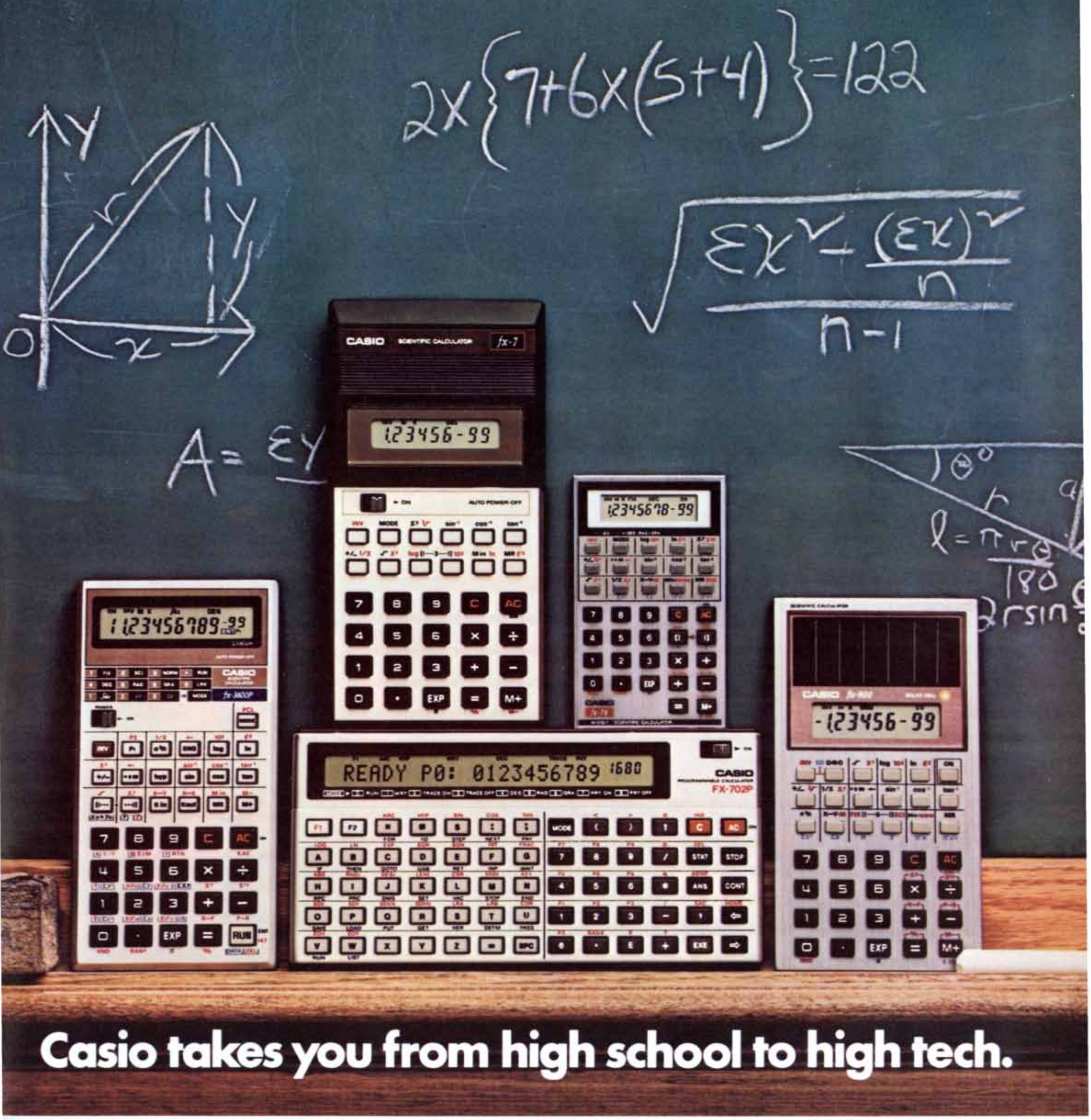
Since World War II there has been a diffusion of household appliances to a large proportion of U.S. households, partly because the appliances cost less in relative terms than they had earlier. There has also been a dramatic increase in the number of married women who work, in both the middle class and the working class. The evidence nonetheless indicates that economic pressures and not free time propel most women into the labor force. If anything, it is the desire for household appliances rather than their possession that provides some of the motivation for women to work. Their goal is to earn enough money to buy appliances that promise to lighten the double burden of wage work and housework. The evidence confirms Oppenheimer's suggestion that "the great increase in laborsaving devices and services [is] a response to a rise in female labor participation" and not the cause of wage-earning work.

Although the ownership of household machinery can lighten a working woman's domestic responsibilities, it does not by any means eliminate household work. Married working women continue to reconcile domestic work and wage earning as their predecessors did in the preindustrial era. Data collected in the 1970's show that working women who are married spend an average of about 30 hours a week on housework compared with 50 for full-time housewives. Thus although the burden of housework is reduced somewhat, working women still spend a significant amount of time on domestic and child-rearing tasks. In contrast, the husbands of working wives spend little or no time doing housework. Many married women appear to be trying to manage the combination of wage earning and housework by taking part-time rather than full-time jobs, which perpetuates occupational segregation and the lower status of women in the job market.

In spite of the fact that the past 200 years have constituted a period of rapid technological change there is a surprising continuity between the social and economic position of women at the beginning of the period and at the end. In both blue- and white-collar work mechanization has been associated with the feminization of particular occupations. Industrial machinery has been introduced partly to lower labor costs; employers have drawn on long-standing cultural assumptions about the low value of women's work in designating certain jobs as suitable only for females. The mechanization of the household confirmed the housewife's responsibility for preparing food, buying supplies and keeping things clean in a private family setting. Indeed, mechanization has made these responsibilities more acceptable to middle-class women who would once have relied on servants. There have been changes in the location of women's work and in the level of drudgery involved, but the changes have not been revolutionary. There is a predictable pattern in the changes in women's work: each transformation has extended the notion of a location for women's work separate from that for men's work and the notion that women's work is worth less than men's.

My argument is not intended to deny that there have been significant improvements in certain aspects of the position of women in society since the mechanization of work began. In the U.S. and western Europe laws enacted in the 19th century granted women education and property rights; laws enacted in the 20th century granted them the right to vote. Social custom has altered standards of propriety in clothing, public behavior and sexual expression. Women now appear to have more choices and to be freer of repression and control than they were even a generation ago. There are more women training to become lawyers, physicians, university professors or business executives.

Whether such changes alter fundamentally the structure of society or women's position in it is debatable; in any case they are not the direct result of mechanization. Some changes may be indirect consequences of the Industrial Revolution. Industrialization accelerated the decline in the importance of land-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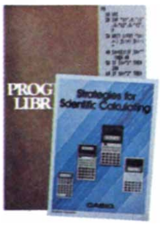
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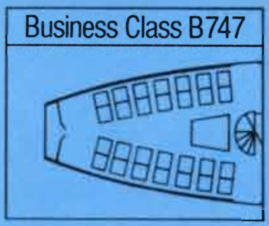
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ed property as the basis for family power. It led to a growing need for educated workers of both sexes and hence for teachers, and it stimulated the growth of the urban population, which needs myriad commercial services and health care. Other changes in the status of women have resulted from the introduction of more reliable methods of contraception; still others result from shifts in the ages at which people marry, bear children and die.

The most important improvements in the position of women, however, have been the result of the actions of women themselves. Such changes have sometimes been responses to mechanization, but they were not inherent in the machines. For example, textile factories brought women workers together under one roof and gave them a sense of the collective power of labor. In so doing the mills created the preconditions for organized expression of labor grievances. Demands for improved conditions and higher wages, however, were formulated by the women themselves; the demands were won only because of the economic and political pressure the organized workers brought to bear on their employers.

Education and, among the middle class, employment led women to demand civil equality, particularly the right to vote. Women won their civil rights, however, only after years of political organizing and (in England and the U.S.) militant public action. Household appliances may have made domestic workers out of middle-class women and so led them into the women's movement in the 1960's and 1970's, but it was the women themselves who formulated the critique of "the feminine mystique." These examples suggest that mechanization did not change the inferior position of women. On the contrary, mechanization emphasized women's social inferiority and led to protests aimed not only at improving particular conditions but also at improving the overall situation of women.

Those who insist that only a revaluation of women's status can lead to greater economic equity and the integration of women into all sectors of the labor market address the problem directly. Until the social and cultural conception of the value of women's work has been changed there can be no revolutionary transformation of women's status as workers. The mechanization of work affects those who work and society at large only through the social context in which the machinery is employed. For women mechanization has confirmed rather than altered their economic and social valuation. In spite of the political and industrial revolutions of recent centuries the revolution for women is yet to come.

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The Distribution of Work and Income

When workers are displaced by machines, the economy can suffer from the loss of their purchasing power. Historically the problem has been eased by shortening the work week, a trend currently at a standstill

by Wassily W. Leontief

"My Lords: During the short time I recently passed in Nottinghamshire not twelve hours elapsed without some fresh act of violence; . . . I was informed that forty Frames had been broken the preceding evening. These machines . . . superseded the necessity of employing a number of workmen, who were left in consequence to starve. By the adoption of one species of Frame in particular, one man performed the work of many, and the superfluous labourers were thrown out of employment. . . . The rejected workmen in the blindness of their ignorance, instead of rejoicing at these improvements in art so beneficial to mankind, conceived themselves to be sacrificed to improvements in mechanism."

With these words Lord Byron in his maiden speech to the House of Lords in February, 1812, sought to explain, and by explaining to excuse, the renewal of the Luddite protest that was shaking the English social order. Nearly a generation earlier Ned Ludd had led his fellow workers in destroying the "frames": the knitting machines that employers had begun to install in the workshops of the country's growing textile industry. The House had before it legislation to exact the death penalty for such acts of sabotage. The Earl of Lauderdale sharpened Byron's thesis that the misled workers were acting against their own interests: "Nothing could be more certain than the fact that every improvement in machinery contributed to the improvement in the condition of persons manufacturing the machines, there being in a very short time after such improvements were introduced a greater demand for labour than ever before."

History has apparently sustained the optimistic outlook of the early exponents of modern industrial society. The specter of involuntary technological unemployment seems to remain no more than a specter. Beginning with the invention of the steam engine, successive waves of technological innovation have brought in the now industrial, or "developed," countries a spectacular growth of both employment and real wages, a combination that spells prosperity and social peace. Thanks as well to technological innovation, more than half of the labor force in all these countries—70 percent of the U.S. labor force—has been relieved from labor in agriculture and other goods-production that employed substantially everyone before the Industrial Revolution. It is true that the less developed countries are still waiting in line. If the outlook for the future can be based on the experience of the past 200 years, those countries too can expect to move up, provided their governments can succeed in reducing their high rate of population growth and desist from interfering with the budding of the spirit of free private enterprise.

There are signs today, however, that past experience cannot serve as a reliable guide for the future of technological change. With the advent of solid-state electronics, machines that have been displacing human muscle from the production of goods are being succeeded by machines that take over the functions of the human nervous system not only in production but in the service industries as well, as has been shown in the preceding articles in this issue of *Scientific American*. The relation between man and machine is being radically transformed.

The beneficence of that relationship is usually measured by the "productivity" of labor. This is the total output divided by the number of workers or, even better, by the number of man-hours required for its production. Thus 30 years ago it took several thousand switchboard operators to handle a million long-distance telephone calls; 10 years later it took several hundred operators, and now, with automatic switchboards linked automatically to other automatic switchboards, only a few dozen are needed. Plainly the productivity of labor—that is, the number of calls completed per operator—has been increasing by leaps and bounds. Simple arithmetic shows that it will reach its highest level when only one operator remains and will become incalculable on the day that operator is discharged.

STOCKHOLDERS' MEETING (*Hauptversammlung*) of Volkswagenwerk AG in West Germany exemplifies an institution of the

The inadequacy of this conventional measure is perhaps better illustrated if it is applied to assess the effects of the progressive replacement of horses by tractors in agriculture. Dividing the successive annual harvest figures first by the gradually increasing number of tractors and then by the reciprocally falling number of horses yields the paradoxical conclusion that throughout this time of transition the relative productivity of tractors tended to fall while the productivity of the horses they were replacing was rising. In fact, of course, the cost-effectiveness of horses diminished steadily compared with that of the increasingly efficient tractors.

In the place of such uncertain abstractions it is more productive to try to bring the underlying facts into consideration and analysis. Technological change can be visualized conveniently as change in the cooking recipes—the specific combinations of inputs—followed by different industries to produce their respective outputs. Progress in electromechanical technology enabled the telephone company to replace the old technological recipe calling for a large number of manual switchboards having many operators with a new recipe combining more expensive automatic switchboards having fewer operators. In agriculture technological progress brought the introduction of successive input combinations with smaller inputs of animal and human labor and larger and more diversified inputs of other kinds—not only mechanical equipment but also pesticides, herbicides, vaccines, antibiotics, hormones and hybrid seed.

New recipes come into service in every industry by a constant process of "costing out." Some inputs included in a new recipe are at the outset too expensive, and it takes some time before improvements in their design or in the method of their manufacture bring sufficient reduction in their price and consequently in the total cost of the recipe to allow the adoption of the new technology. The decline, at the nearly constant rate of 30 percent per year for many years, in the cost per memory bit on the integrated-circuit chip has brought solid-state electronics technology first into expensive capital equipment such as telephone switchboards, automatic pilots, machine tools and computers, then into radio and television sets and powerful, low-cost computers as an entirely new category of consumer goods, then into the control systems of automobiles and household appliances and even into such expendable goods as toys. Thus the adoption of a new recipe in one industry often depends on replacement of the old by a new technology in another industry, as the vacuum tube was replaced by the transistor and its descendants in the transformed electronics industry.

Stepping back and contemplating the flow of raw materials and intermediate products through the input-output structure of an industrial system and the corresponding price structure, one can see that prices more or less faithfully reflect the state of technology in the system. With the passage of time price changes can be expected to reflect long-run technological changes going on in the various sectors. In this perspective human labor of a specific kind appears as one, but only one, of the many different inputs the price of which must be reckoned in the costing out of a given

West German economy: close collaboration between capital and labor. The West German "codetermination" law requires that half of the board of directors of each large corporation be elected by labor and the other half by the stockholders. At this meeting of Volkswagen, held on July 1, the directors and the managers of the company are on the dais giving reports to stockholders and answering questions.

technological recipe. Its price, the wage rate, enters into the cost comparisons between competing technologies in the same way as the price of any other input.

In the succession of technological changes that have accompanied economic development and growth, new goods and services come on the stage and old ones, having played their role, step off. Such changes proceed at different rates and on different scales, affecting some sectors of economic activity more than others. Some types of labor are replaced faster than others. Less skilled workers in many instances, but not always, go first, more skilled workers later. Computers are now taking on the jobs of white-collar workers, performing first simple and then increasingly complex mental tasks.

Human labor from time immemorial played the role of principal factor of production. There are reasons to believe human labor will not retain this status in the future.

Over the past two centuries technological innovation has brought an exponential growth of total output in the industrial economies, accompanied by rising per capita consumption. At the same time, until the middle 1940's the easing of man's labor was enjoyed in the progressive shortening of the working day, working week and working year. Increased leisure (and for that matter cleaner air and purer water) is not counted in the official adding up of goods and services in the gross national product. It has nonetheless contributed greatly to the well-being of blue-collar workers and salaried employees. Without increase in leisure time the popularization of education and cultural advantages that has distinguished the industrial societies in the first 80 years of this century would not have been possible.

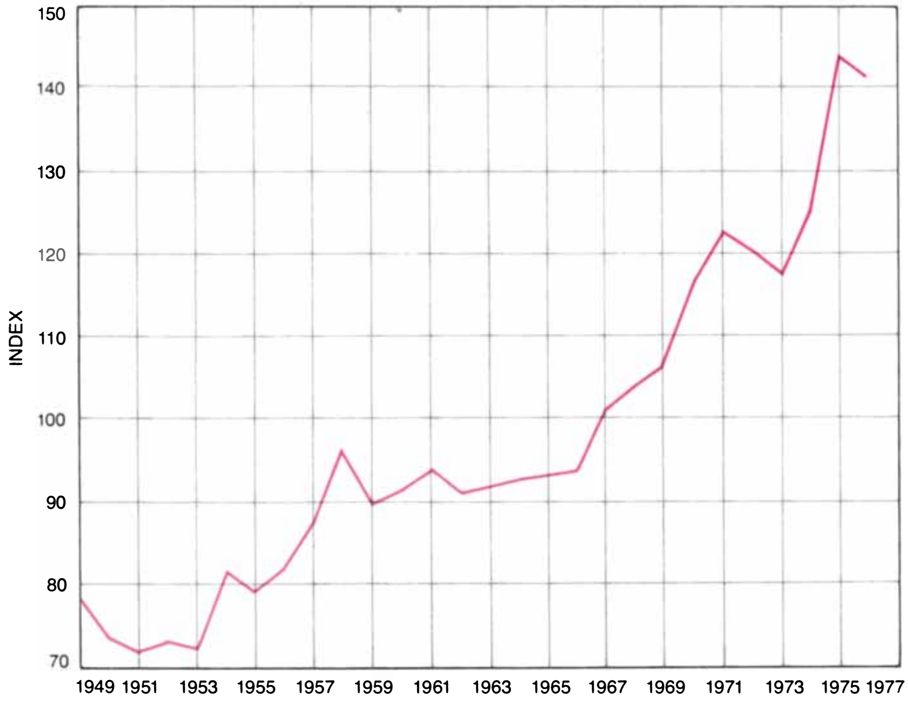
The reduction of the average work week in manufacturing from 67 hours in 1870 to somewhat less than 42 hours must also be recognized as the withdrawal of many millions of working hours from the labor market. Since the end of World War II, however, the work week has remained almost constant. Waves of technological innovation have continued to overtake each other as before. The real wage rate, discounted for inflation, has continued to go up. Yet the length of the normal work week today is practically the same as it was 35 years ago. In 1977 the work week in the U.S. manufacturing industries, adjusted for the growth in vacations and holidays, was still 41.8 hours.

Concurrently the U.S. economy has seen a chronic increase in unemployment from one oscillation of the business cycle to the next. The 2 percent accepted as the irreducible unemployment rate by proponents of full-employment legislation in 1945 became the 4 percent of New Frontier economic managers in the 1960's. The country's unemployment problem today exceeds 9 percent. How can this be explained?

Without technological change there could, of course, be no technological unemployment. Nor would there be such unemployment if the total population and the labor force, instead of growing, were to shrink. Workers might also hang on to their jobs if they would agree to accept lower wages. Those who are concerned with population growth are likely to proclaim that "too many workers" is the actual cause of unemployment. Libertarians of the "Keep your hands off the free market" school urge the remedy of wage cuts brought about by the systematic curtailment of the power of trade unions and the reduction of unemployment and welfare benefits. Advocates of full employment have been heard to propose that labor-intensive technologies be given preference over laborsaving ones. A more familiar medicine is prescribed by those who advocate stepped-up investment in accelerated economic growth.

Each of these diagnoses has its shortcomings, and the remedies they prescribe can be no more than palliative at best. A drastic general wage cut might temporarily arrest the adoption of laborsaving technology, even though dirt-cheap labor could not compete in many operations with very powerful or very sophisticated machines. The old trend would be bound to resume, however, unless special barriers were erected against laborsaving devices. Even the most principled libertarian must hesitate to have wage questions settled by cutthroat competition among workers under the pressure of steadily advancing technology. The erection of Luddite barriers to technological progress would, on the other hand, bring more menace to the health of the economic and social system than the disease it is intended to cure.

Increased investment can certainly provide jobs for people who would otherwise be unemployed. Given the rate of technological advance, the creation of one additional job that 20 years ago might have required an investment of $50,000 now demands $100,000 and in 20 years will demand $500,000, even with inflation discounted. A high rate of investment is, of course, indispensable to the expanding needs of a growing economy. It can make only a limited contribution to alleviating involuntary technological unemployment, however, because the greater the rate of capital investment, the higher the rate of introduction of new laborsaving technology. The latest copper smelter to go into service in the U.S. cost $450 million and



VALUE OF CAPITAL STOCK employed per man-hour in manufacturing industries in the U.S., plotted here on a constant 1967-dollar index, has almost doubled since the end of World War II. In this period the total output per capita of U.S. manufacturing industries also more than doubled. With a constant work week over this period (*see illustration on page 192*) and an increase of only 4 percent in the blue-collar factory work force, from 12.8 to 13.3 million, the increase in output must be attributed almost entirely to the introduction of new technology embodied in the expanding capital stock of the industries. The development of the technology in these capital inputs is one of the functions of the white-collar "nonproduction" work force in the manufacturing industries, which in the same period more than doubled in number, from fewer than three million workers to nearly six million. The chart may also be taken as plotting the rising capital cost of creating a new job in U.S. manufacturing industries.

This is Thomas. One day, he might win the Nobel Prize. Or perhaps he'll even get a job. (Anything's possible, after all.)

But for two hours last Autumn, all his glorious futures hung in the balance.

He contracted an infection. His temperature soared and he fell into convulsions.

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Now, thanks to the national radio paging system, a doctor can be alerted to an emergency by a 'bleep,' carried about his person, enabling him to save vital minutes in the treatment of serious illness.

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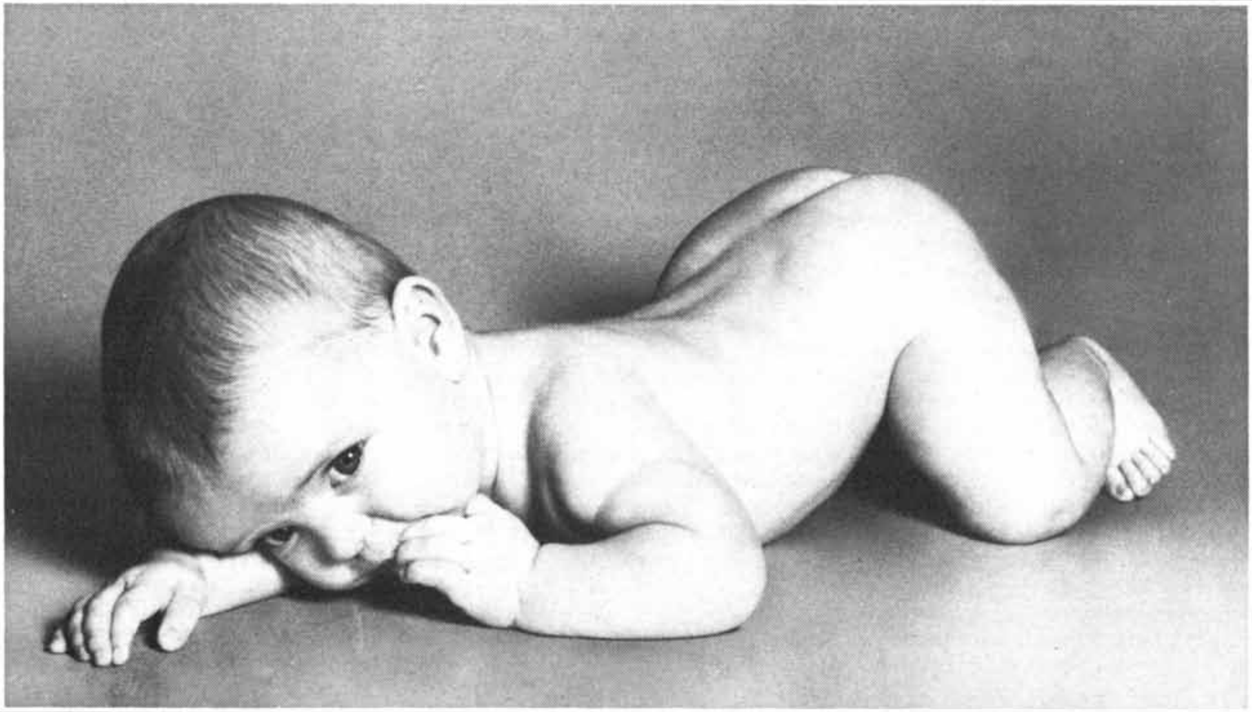

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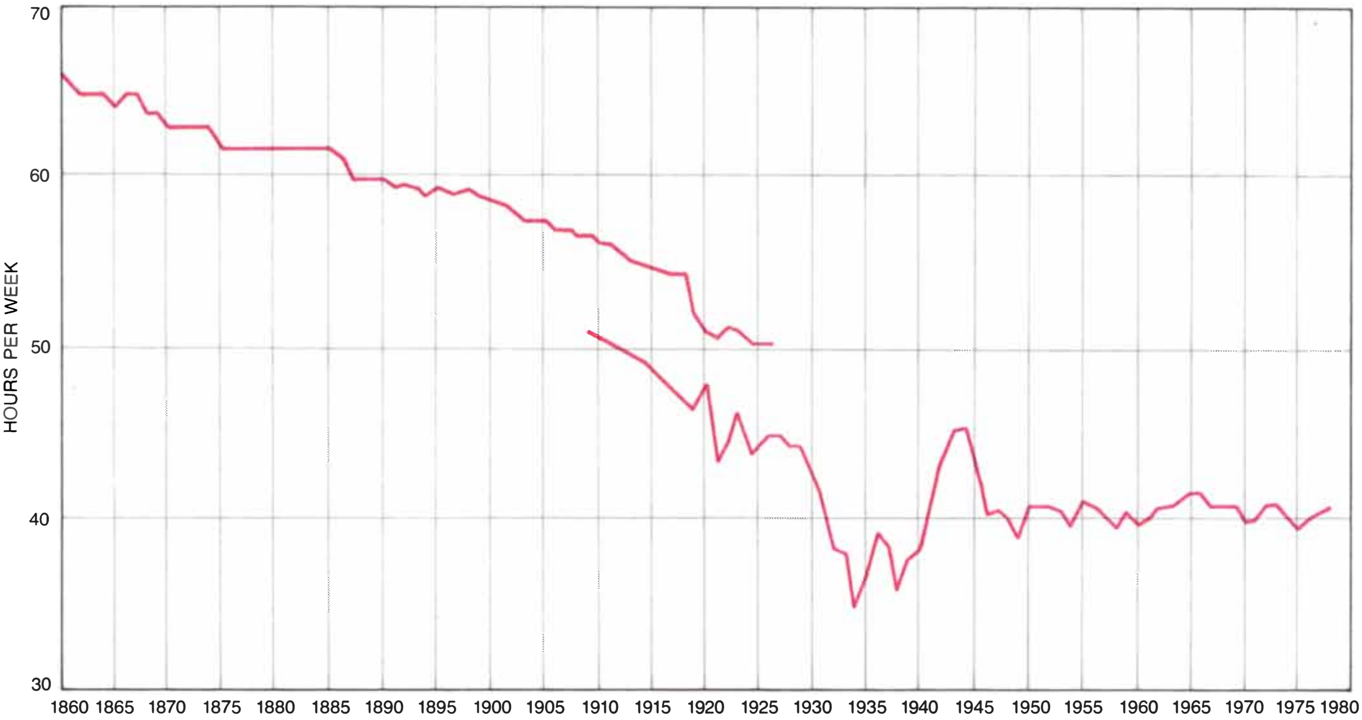

WORK WEEK IN MANUFACTURING INDUSTRIES of the U.S. shortened from about 67 hours in 1860 to about 42 hours in 1950 and has remained constant since then. Such reduction in the average number of working hours per week per employee amounts to the withdrawal from work of more than a third of the manufacturing labor force. The work week actually fell below 40 hours in the Great Depression of the 1930's with "sharing of unemployment" in part-time jobs and climbed well above 40 hours with overtime work in war production in the 1940's. The shortening of the work week together with income policies to maintain and increase, as the increase in output allows, the take-home income of the labor force constitutes one strategy for offsetting technological unemployment (*see illustrations on pages 202 and 204*). The discontinuity in the curve, over the period 1910 through 1925, reflects a change in the statistical time series kept by the country's bookkeepers involving principally changes in their accounting of the time of part-time and seasonal workers.

employs fewer than 50 men per shift.

Americans might have continued to absorb potential technological unemployment by voluntary shortening of the work week if real wages had risen over the past 40 years faster than they actually have, allowing the expectation of increase not only of total annual pay but also of total lifetime take-home pay. Because of the greatly expanded opportunities to replace labor by increasingly sophisticated technology it appears that the impersonal forces of the market no longer favor that possibility. Government policies directed at encouraging a steady rise in real wages sufficiently large to induce workers to resume continuous voluntary reduction in the work week could once have been considered. Under present conditions such policies would require such a large increase in the share of total national income going to wages that it would bring decline in productive investment, which is financed largely by undistributed corporate earnings and the savings of the upper income group. This would result in an unacceptable slowdown of economic growth. There remains the alternative of direct action to promote a progressive shortening of the work week combined with income policies designed to maintain and to increase, as increases in total output allow, the real family income of wage earners and salaried employees.

Recent studies sponsored by the U.S. Department of Labor seem to indicate that the total number of working hours offered by the existing labor force might be reduced in exchange for a more flexible scheduling of work time. Indeed, some workers, depending on their age group, family status, occupation and so on, would even be prepared to forgo a certain fraction of their current income, some by extension of their annual vacation, some by earlier retirement or sabbatical leave and some by working four and a half days per week instead of five. Reducing the work day by 15 minutes proves, incidentally, to be one of the less desirable alternatives. Tentative and obviously somewhat speculative computations based on the most desirable trade-off choices for different groups developed in these studies indicate that the average U.S. worker would be willing to forgo some 4.7 percent of earnings in exchange for free time. On the basis of the 1978 work year the average employee's work time would be reduced from 1,910 work hours to 1,821, or by more than two working weeks in a year.

Although such measures certainly deserve serious consideration and, if at all possible, practical implementation, they cannot provide a final answer to the long-run question of how to enable a modern industrial society to derive the benefits of continued technological progress without experiencing involuntary technological unemployment and resulting social disruption. Sooner or later, and quite probably sooner, the increasingly mechanized society must face another problem: the problem of income distribution.

Adam and Eve enjoyed, before they were expelled from Paradise, a high standard of living without working. After their expulsion they and their successors were condemned to eke out a miserable existence, working from dawn to dusk. The history of technological progress over the past 200 years is essentially the story of the human species working its way slowly and steadily back into Paradise. What would happen, however, if we suddenly found ourselves in it? With all goods and services provided without work, no one would be gainfully employed. Being unemployed means receiving no wages. As a result until appropriate new income policies were formulated to fit the changed technological conditions everyone would starve in Paradise.

The income policies I have in mind do not turn simply on an increase in the legally fixed minimum wage or in the hourly wage or other benefits negotiated by the usual collective bargaining between trade unions and employers. In

SCIENCE/SCOPE

More than 4,500 men and women have furthered their professional careers through the Hughes Fellowship Programs since 1949. Those who qualify are given the opportunity to earn advanced degrees in scientific and engineering disciplines. Under full-study programs, employees study at selected schools and work at a company facility during the summer. Under work-study programs, employees work part-time and carry about one-half of a full academic load at nearby schools. More than 100 fellowships are awarded annually.

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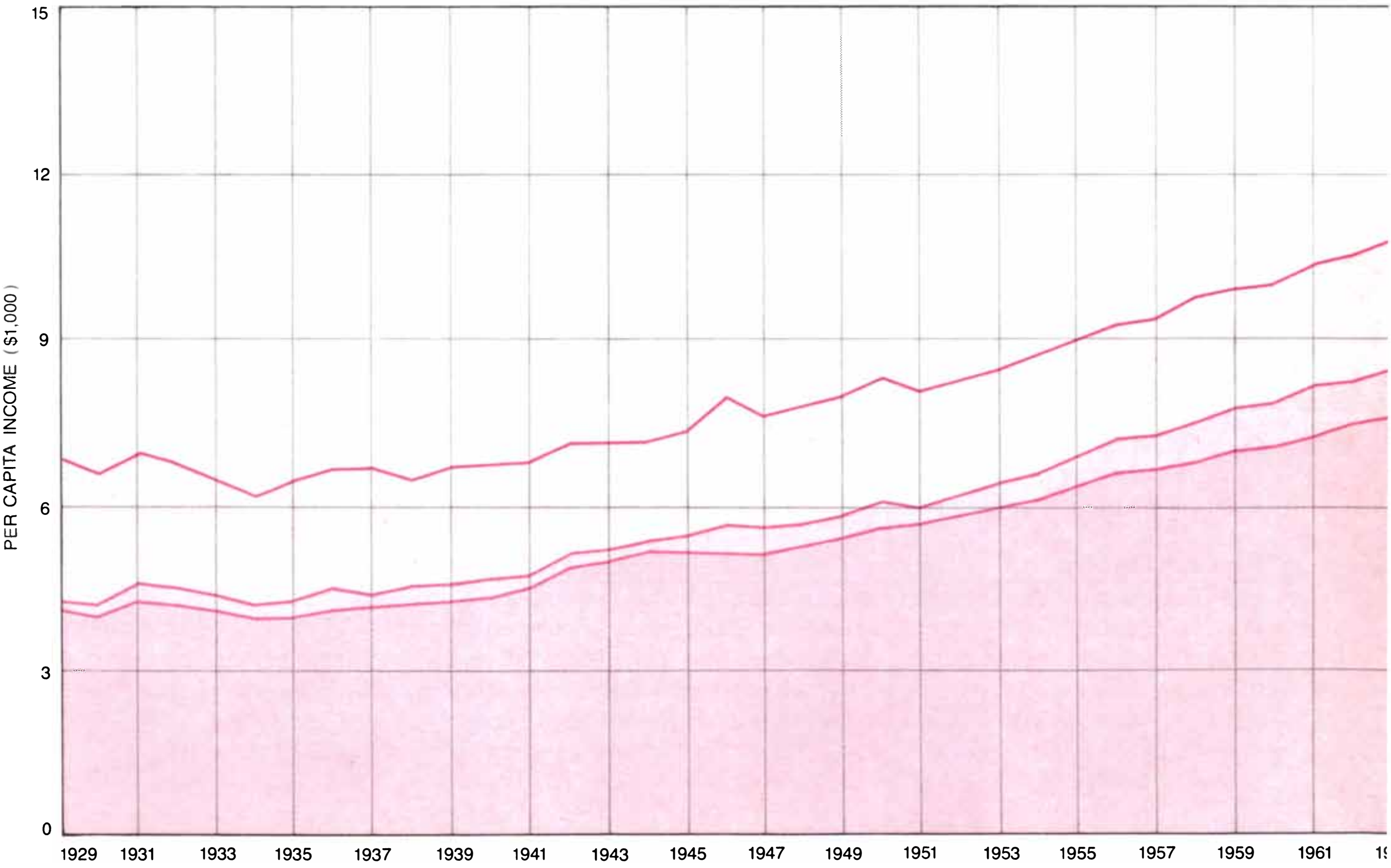
the long run increases in the direct and indirect hourly labor costs would be bound to accelerate laborsaving mechanization. This, incidentally, is the explicitly stated explanation of the wage policies currently pursued by the benevolently authoritarian government of Singapore. It encourages a rapid rise in real wages in order to induce free domestic enterprise to upgrade the already remarkably efficient production facilities of this city-state. It is perhaps needless to add that these policies are accompanied by strict control of immigration and encouragement of birth control.

What I have in mind is a complex of social and economic measures to supplement by transfer from other income shares the income received by blue- and white-collar workers from the sale of their services on the labor market. A striking example of an income transfer of this kind attained automatically without government intervention is there to be studied in the long-run effects of the mechanization of agriculture on the mode of operation and the income of, say, a prosperous Iowa farm. Half a century ago the farmer and the members of his family worked from early morning until late at night assisted by a team of horses, possibly a tractor and a standard set of simple agricultural implements. Their income consisted of what essentially amounted to wages for a 75- or 80-hour work week, supplemented by a small profit on their modest investment.

Today the farm is fully mechanized and even has some sophisticated electronic equipment. The average work week is much shorter, and from time to time the family can take a real vacation. Their total wage income, if one computes it at the going hourly rate for a much smaller number of manual-labor hours, is probably not much higher than it was 50 years ago and may even be lower. Their standard of living, however, is certainly much higher: the shrinkage of their wage income is more than fully offset by the income earned on their massive capital investment in the rapidly changing technology of agriculture. The shift from the old income structure to the new one was smooth and practically painless. It involved no more than a simple bookkeeping transaction because now, as 50 years ago, both the wage income and the capital income are earned by the same family.

The effect of technological progress on manufacturing and other nonagricultural sectors of the economy is essentially the same as it is on agriculture. So also should be its repercussions with respect to the shortening of the work day and the allocation of income. Because of differences in the institutional setup, however, those repercussions cannot be expected to work through the system automatically. That must be brought about by carefully designed income policies. The accommodation of existing institutions to the demands and to the effects of laborsaving mechanization will not be easy. The setting aside of the Puritan "work ethic," to which Max Weber so convincingly ascribed the success of early industrial society, is bound to prove even more difficult and long drawn out. In popular and political discourse on employment, full employment and unemployment, with its emphasis on the provision of incomes rather than the production of goods, it can be seen that the revision of values has already begun.

The evolution of institutions is un-

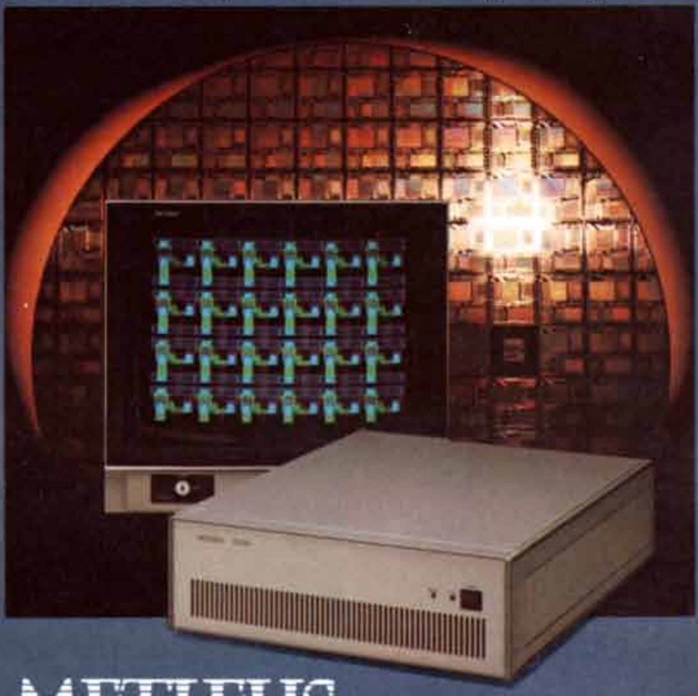


PERSONAL INCOME PER CAPITA in the U.S., plotted here in constant 1972 dollars, has more than doubled since 1929. The change in percentage shares of income accruing from property, transfer payments and labor (or to people receiving such income) reflects the evolution of the values and institutions of American society. The curves show that income from property has declined from about 40 percent to not much more than 15 percent of total personal income. Some of that decline reflects the exchange of profit and interest from small businesses (notably in trade and distribution and the services) for wages in large business enterprises (income from labor). It also reflects increased retention of earnings in corporations and increased financing of investment by such deflection of savings from person-

der way as well. In the structure of the tax system and through Social Security, medical insurance, unemployment benefits and welfare payments the country is finding its way toward necessary income policies. A desirable near-term step is to reduce the contrast between those who are fully employed and those who are out of work. This is the effect of the widespread European practice of paying supplemental benefits to those who work fewer than the normal number of hours per week. In the long run, responding to the incipient threat of technological unemployment, public policy should aim at securing equitable distribution of work and income, taking care not to obstruct technological progress even indirectly.

Implementation of such policy calls for close and systematic cooperation between management and labor carried on with government support. Large-scale financial transfers inevitably generate inflationary pressure. The inflation that dogs all the market economies, some more than others, does not arise from mere technical economic causes but is the symptom of deep-seated social problems. In this country it is basically

al income. Income from labor has increased from about 60 percent of the total to about 70 percent. Income from transfer payments (Social Security, medical benefits, unemployment compensation and so on) was negligible in 1929 but now is about 15 percent of total.

Physician, did you miss any of these significant developments in medical science?

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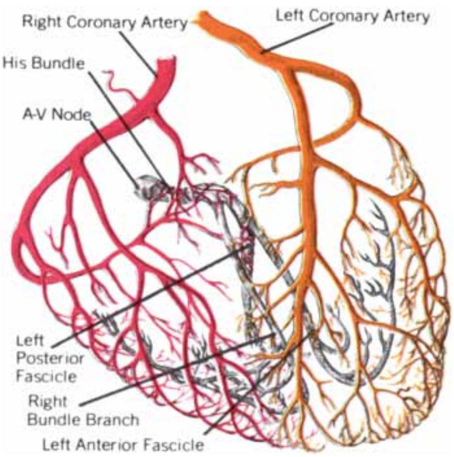

Branches of the right and left coronary arteries supply blood to the A-V node and intraventricular conduction system.

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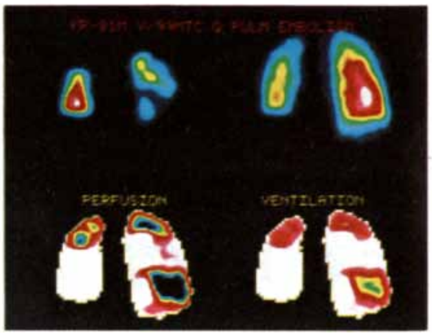
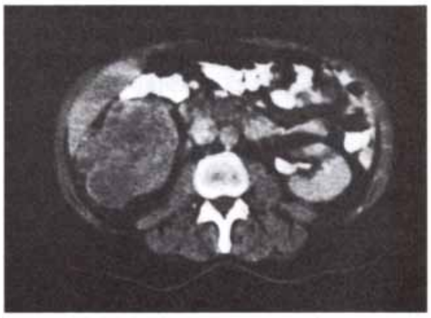


Computerized scintigraphy reveals pulmonary thromboembolism.



Abdominal computed tomogram reveals large renal carcinoma replacing part of right kidney.

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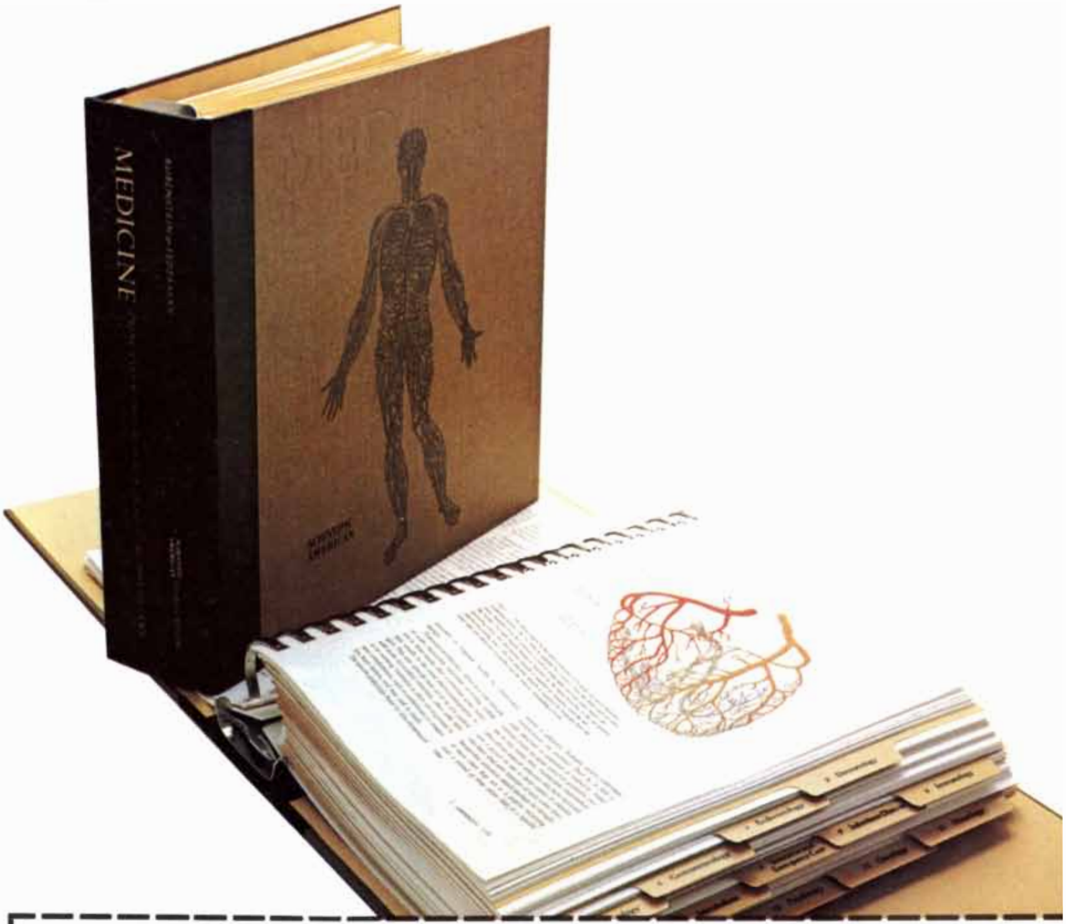

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EXTRACTIVE (BUSHELS)		25	20	55	100
MANUFACTURING (TONS)		14	6	30	50
HOUSEHOLDS	LABOR (HOURS)	70	140		210
	CAPITAL (TONS)	10	40		50

		EXTRACTIVE	MANUFACTURING	HOUSEHOLDS	TOTAL
EXTRACTIVE (BUSHELS)		31	32	62	125
MANUFACTURING (TONS)		38	16	26	80
HOUSEHOLDS	LABOR (HOURS)	50	80		130
	CAPITAL (TONS)	135	100		235

INPUTS AND OUTPUTS IN DOLLAR VALUES

		EXTRACTIVE	MANUFACTURING	HOUSEHOLDS	TOTAL
EXTRACTIVE		50	40	110	200
MANUFACTURING		70	30	150	250
HOUSEHOLDS	WAGES	70	140		210
	PROFITS	10	40		50
TOTAL		200	250	260	

		EXTRACTIVE	MANUFACTURING	HOUSEHOLDS	TOTAL
EXTRACTIVE		94	96	185	375
MANUFACTURING		150	64	106	320
HOUSEHOLDS	WAGES	50	80		130
	PROFITS	81	80		161
TOTAL		375	320	291	

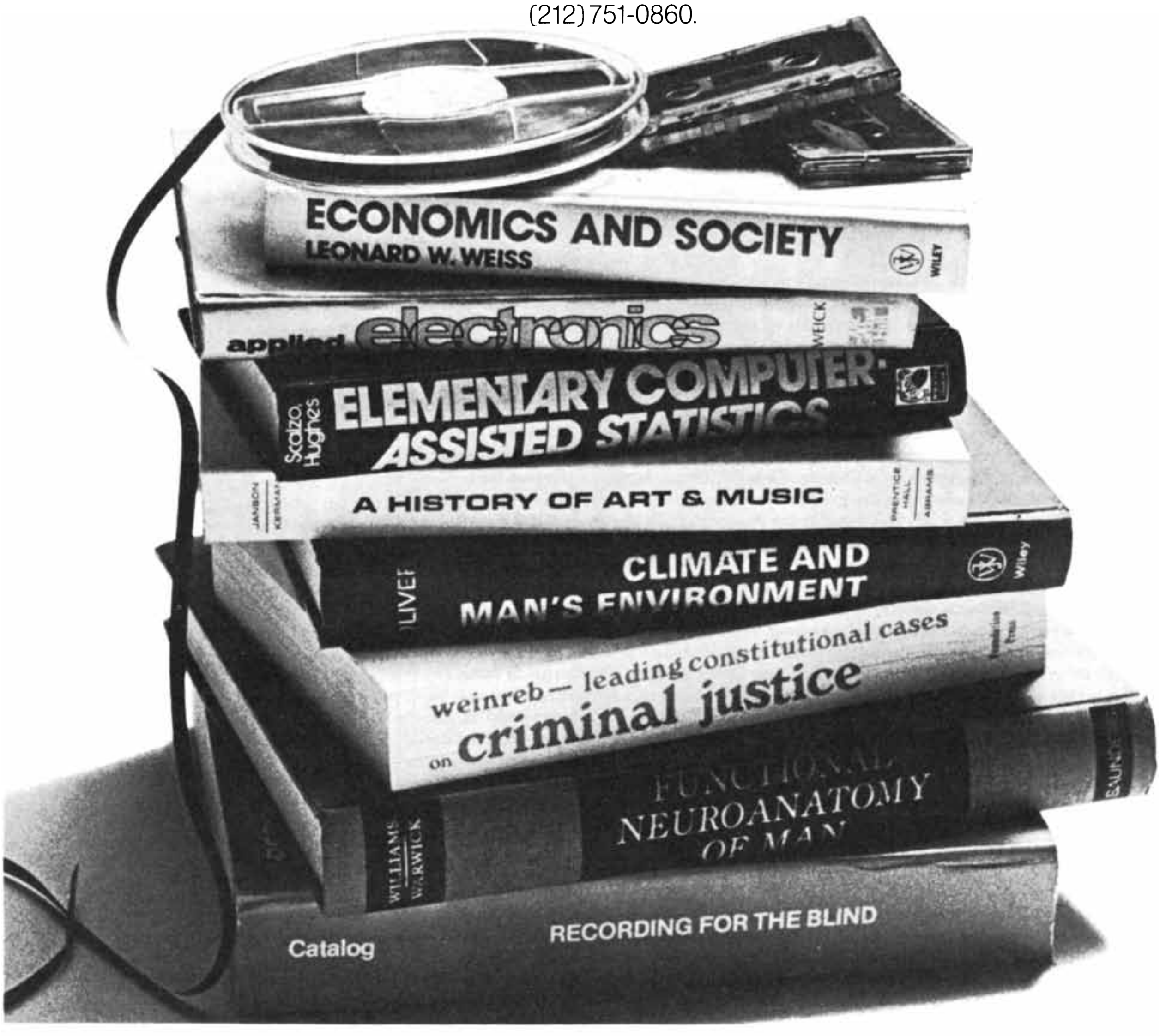
the incessant wrangling between management and labor that keeps the cost-price spiral climbing.

West Germany, a country celebrated for its successful stabilization policies, is touted also as an example of the unregulated enterprise economy. In reality the success of the Schmidt government's anti-inflation measures rests on the firm foundation of institutionalized labor-capital cooperation in the management of German industry. The "codetermination" law requires that half of the board of directors of each large corporation be elected by labor, with the stockholders represented by the other half. Among the labor members some are "outside" directors representing the national trade unions. Since wage and employment questions constitute only one problem in the broad range of problems on the agenda of these boards, their deliberations bring employers and employees into working contact at the grass roots of German industry. That relationship cannot but be of crucial importance in determining the nature of agreements reached in collective bargaining conducted between the parties at the national level.

Austria is another country that has up to now successfully resisted inflationary pressure. Relations between management and labor are mediated by institutional arrangements very similar to those in Germany. The government plays a larger and more active role in the national across-the-board wage negotiations. It does so by contributing projections, drawn from the input-output data bank of the country's bookkeeping system, that link decisions affecting the industry in question to the situation of the country as a whole. This approach was employed, for example, to model and project the impact of the new text-processing and printing technologies on the Austrian newspaper industry. That technological revolution, the occasion for months-long disputes and work stoppages in Britain, the U.S. and other countries, was carried out smoothly and expeditiously in Austria by close cooperation between management and labor in accordance with detailed plans developed by the government. Until 1980, when the tidal wave of the second oil crisis, reinforced by the recession in the U.S. economy, reached Austria, the annual rate of inflation had been held below 4 percent and unemployment below 2 percent.

Although current business publications, trade papers and the popular press abound with articles about "automation" and "robotics" and speculation on the economic impact of these developments, only the governmental and scientific agencies of Austria have produced a systematic assessment of the prospective consequences of the present revolution in laborsaving technology in a modern industrial economy and society. That study, conducted for the government by the Austrian Academy of Sciences and the Austrian Institute for Economic Research, employed the country's input-output data bank to con-

INPUT-OUTPUT STRUCTURE of a rudimentary model economy is employed here to demonstrate the application of input-ouput analysis to assessment of the impact of mechanization on employment in an economic system. The two sets of three input-ouput tables show the system before mechanization (*left*) and afterward (*right*). For simplicity the model economy is disaggregated into two producing sectors, "Extractive" and "Manufacturing," and a "Households" sector that supplies labor and capital to the producing sectors; a real economy would be disaggregated into as many sectors as the data allow. The "Input-output coefficient" tables at the top of each set display the ratios of the inputs entered in the column for any sector in the tables of "Inputs and outputs in physical units," second from the top, to the total output entered at the end of the row for that sector in those tables. Thus the input-ouput coefficient table before mechanization, at the left, shows that the production of each ton of output from the manufacturing sector requires the input of .40 bushel from the extractive sector and .12 ton of its own product plus 2.80 hours of labor and .80 ton of capital stock (consisting of manufactured goods) provided by the households sector. Such coefficients may be derived from the record of actual transactions or from engineering data and other data and may be used to generate a new commodity flow table satisfying a different set of input demands in the households column. With prices at $2 per bushel, $5 per ton and $1 per hour and a return on capital at 20 percent of the value of the capital stock (physical units times price), the columns and rows in the "Inputs and outputs in dollar value" table, at the bottom left, can now be added and shown to balance: the value of the inputs equals the value of the outputs. The households row and column can be considered as being outside the interindustry matrix: the entries in its row correspond to the value-added of each industry; the entries in its column correspond to deliveries of each industrial sector to final demand. The equal totals of the households row and column correspond to the gross national product on the production and consumption sides respectively: $260 in the table at the left. In the tables at the right aggressive investment in laborsaving mechanization is assumed. Substantial increase in the coefficients for capital stock in both the extractive and the manufacturing sectors is reflected in increase in total capital stock from 50 tons to 235 tons in the physical units of the middle table. The consequent reduction in labor coefficients is reflected in the reduction of the labor input from 210 hours to 130. In spite of the increase in the price of extractive outputs to $3 per bushel, owing to increasing resource scarcities, the more efficient model economy now produces manufacturing outputs at the reduced price of $4 per ton and raises its gross national product to $291. With reduced employment, however, labor income falls from $210 to $130. The maintenance of consumption would therefore require deflection of income within the households sector from return on capital to labor income and income transfers, as in the real U.S. economy (*see illustration on pages 194 and 195*).



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	JOBS AFFECTED	REDUCTION IN LABOR INPUT	JOBS AFFECTED 1990	REDUCTION IN EMPLOYMENT	JOBS AFFECTED	REDUCTION IN LABOR INPUT	JOBS AFFECTED 1990	REDUCTION IN EMPLOYMENT
AGRICULTURE AND FORESTRY	—	—	—	—	.01	.50	.200	.001
MINING	.68	.50	.072	.025	.10	.50	.038	.019
PETROLEUM	.60	.50	.235	.059	.20	.50	.076	.008
GLASS	.60	.50	.069	.021	.12	.50	.059	.008
FOOD PROCESSING	.55	.50	.114	.031	.10	.50	.154	.008
TEXTILES	.85	.67	.390	.222	.10	.50	.208	.010
CLOTHING	.89	.67	.210	.125	.07	.50	.177	.004
CHEMICALS	.55	.67	.300	.111	.20	.50	.206	.021
BASIC METALS	.73	.50	.369	.135	.13	.50	.182	.012
MACHINERY	.70	.77	.480	.259	.13	.50	.219	.014
METAL PRODUCTS	.80	.67	.215	.115	.13	.50	.195	.013
ELECTRICAL INDUSTRY	.65	.67	.700	.305	.13	.50	.220	.014
TRANSPORTATION EQUIPMENT	.50	.67	.352	.118	.13	.50	.219	.014
FOREST PRODUCTS	.75	.67	.075	.038	.10	.50	.118	.006
WOODWORKING	.75	.67	.075	.038	.10	.50	.118	.006
PAPER MANUFACTURE	.85	.67	.400	.228	.12	.50	.464	.028
PAPER PRODUCTS	.85	.50	.429	.182	.12	.50	.374	.022
CONSTRUCTION	—	—	—	—	.07	.50	.200	.007
ELECTRIC, GAS, WATER UTILITIES	.23	.50	.235	.027	.22	.50	.200	.022
TRADE	.53	.80	.100	.042	.18	.50	.200	.018
INFORMATION INDUSTRY	.41	.67	.020	.005	.11	.50	.200	.022
BANKS AND INSURANCE	—	—	—	—	.70	.50	.400	.140
HOTELS AND RESTAURANTS	—	—	—	—	.02	.50	.200	.002
OTHER SERVICES	—	—	—	—	.12	.50	.200	.012
HOUSING	—	—	—	—	—	1.00	0	—
GOVERNMENT	—	—	—	—	.64	.50	.180	.058

IMPACT OF MECHANIZATION ON JOBS in Austria is projected, industry by industry, from estimates made by engineers and other experts for an input-output study of the effects of mechanization on the Austrian economy (*see illustration on page 204*). The first column, under both the blue-collar and the white-collar headings, shows the percentage of jobs potentially affected by technology demonstrated as of 1980 although not yet installed on the production line or in the office; the second column shows the percentage of reduction of labor input in those functions potentially affected by such new technology; the third column shows the estimated percentage of jobs that would be displaced by 1990 if there were full application of the technology, and the fourth column shows the prospective percentage reduction in employment in 1990 that is the resultant of the other three percentages. Note the large percentage of blue-collar jobs potentially affected compared with the almost invariably small number of white-collar jobs affected, and the larger (in most cases) prospective reduction of labor input in blue-collar production functions compared with the uniform 50 percent reduction in white-collar office functions expected to result from the application of essentially the same technology to clerical and stenographic jobs in all industries and services.

struct a model of the Austrian economy as of 1976. The model was then used to develop, in the words of Hertha Firnberg, the minister for science, in her introduction to the report of the study [see "Bibliography," page 218], "instead of unconditional prognostications—of either jubilation or horror—projections in the form of alternative scenarios . . . to analyze in quantitative terms the combined effects of economic, social and educational policy measures."

In input-output analysis the interindustry transactions that go into the production of the output of an economic system are arrayed in a matrix, with the outputs of each industrial sector displayed along its row and the inputs it draws from other industries in its column. The ratio of each input to the output of the sector—the input-output coefficient—reflects the technological requirement for that input which, although it is usually expressed in monetary value, is best visualized in the physical units appropriate to it, whether tons, bushels, barrels, kilowatts or man-hours [*see illustration on page 198*]. The entire column of input-output coefficients therefore presents the recipe of inputs required by the prevailing state of the technology involved in the production of that industry's product. At the foot of the column the human input is specified by the different kinds of labor supplied by the household sector.

For the Austrian study new sets of input-output coefficients had to be constructed reflecting changes in the input structure of all sectors of the economy prospectively dictated by the adoption of new laborsaving technology. In the simulation runs the effects of these changes could be gauged by comparison with the figures derived from actual interindustry transactions for 1976. Information for construction of the new coefficients was procured by comprehensive questionnaires circulated to technologists in each field and interviews with responsible technical directors of major industrial and service enterprises.

With all these data installed in the model, five alternative projections were run, describing in great detail the prospective state of the Austrian economy in the years 1985 and 1990. The sets of assumptions governing the projections differ from one another with respect to the rate of adoption of laborsaving technology, the extent of reliance on domestic as opposed to foreign suppliers of the new equipment, the more or less optimistic appraisal of the state of the world economy and last but not least the length of the work week for its effect on the distribution of employment among different sectors and the rate of unemployment.

Out of the wealth of thought-provoking indications for the future to be found by close inspection of the several projec-

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tions, it suffices for the purposes of the present discussion to cite just a few. The projections that carry the present state-of-the-art laborsaving technology into full application everywhere in the Austrian economy by 1990 lead in all cases to the largest increase in gross domestic product—but also to the highest levels of unemployment, to unemployment of 10 percent, a level not experienced in Austria since the dark days of the 1930's. With curtailment in the length of the work week at the maximum degree of mechanization, the direction of both the positive and the negative changes remains the same but their absolute magnitudes are reduced. Unemployment in this case comes closer to the civilized Austrian experience of 2 percent.

No comparable study has yet been completed for the U.S. economy. Fiscal starvation of the Federal statistical agencies has them currently sorting out interindustry-transactions data for 1977, with publication scheduled for not sooner than 1984. The Austrian study presents the best model available for projection of conditions in the U.S. of 1990. The Austrian economy is a mere 3 percent the size of the U.S. economy, but it too is highly industrialized and diversified. With some stretch of the imagination the Austrian projection of a high degree of mechanization supported by rapid expansion of domestic manufacture of all kinds of electronic products can be interpreted as indicating the structural changes the U.S. economy is likely to undergo in the next 10 or 15 years.

The time span covered by these projections is short. Moreover, they reckon with the consequences of the application of the state of the art of mechanization only as of 1980 at the latest, a state soon to be made obsolete by rapid advance in all the relevant technologies. These figures nonetheless throw some light on the quantitative dimensions of the profound challenge that an advanced industrial society must now begin to face under the impact of the continuing Industrial Revolution. History, even recent history, shows that societies have responded to such challenge with revision of their economic institutions and values conducive to the efficient use of changing technology and to securing its advantages for popular well-being. History shows also societies that have failed to respond and have succumbed to economic stagnation and increasing social disorder.

	1976 (ACTUAL)	1990 (PROJECTIONS)				
		UNCHANGED WORK WEEK		SHORTENED WORK WEEK		
		NO MECHANIZATION	FULL MECHANIZATION	NO MECHANIZATION	PARTIAL MECHANIZATION	FULL MECHANIZATION
GROSS DOMESTIC PRODUCT (10^9 SCHILLINGS)	738	1,180	1,190	1,113	1,114	1,148
INVESTMENT	197	365	365	365	365	365
PRIVATE CONSUMPTION	416	654	675	596	607	619
PUBLIC CONSUMPTION	133	172	174	162	163	168
EXPORTS	255	619	624	584	585	603
IMPORTS	262	631	648	595	605	606
GROSS DOMESTIC PRODUCT PER EMPLOYED PERSON (10^3 SCHILLINGS)	229	366	390	326	340	341
PER CAPITA WAGES (10^3 SCHILLINGS)	**101**	**150**	**159**	**131**	**136**	**137**
AVERAGE WORK WEEK (HOURS)	**42.1**	**39.6**	**39.9**	**35.2**	**35.3**	**35.3**
UNEMPLOYMENT (1,000 PERSONS)	**55**	**220**	**386**	**29**	**165**	**76**
EMPLOYMENT (1,000 PERSONS)	**3,222**	**3,221**	**3,056**	**3,413**	**3,277**	**3,366**
MEN	1,936	1,883	1,802	2,004	1,934	1,989
WOMEN	1,287	1,338	1,254	1,409	1,343	1,376

IMPACT OF MECHANIZATION ON ECONOMY of Austria in 1990 was projected in constant 1976 Austrian schillings by computer runs of a numerical matrix model of the input-output structure (*see illustration on page 198*) of the economy. The computer runs explored different sets of assumptions incorporated in the model to produce these columns of figures comparing the resultant differences in essential features of the system. The column at the far left shows the actual state of the economy in 1976. Under "Unchanged work week" the first column shows the economy projected to 1990 on the assumption of no change in the degree of mechanization already attained in 1976; the second column shows the economy projected on the assumption that mechanization employing technology demonstrated at the time of the study (1980) and embodied in largely imported equipment will have the full impact on jobs displayed in the table on page 202. Under "Shortened work week" the three columns from left to right show projections on the assumption (1) of no change from the 1976 state of mechanization, (2) of partial mechanization, that is, the realization (again with largely imported equipment) of 50 percent of the job impact displayed in the table on page 202 and (3) of full mechanization with equipment largely produced within the economy. Inspection shows that full mechanization with the work week unchanged yields the largest gross national product in 1990 (although only 10 million schillings larger than the projection based on 1976 mechanization), but it also causes the largest increase in unemployment. Shortening of the work week reduces the unemployment level in 1990 to around 2 percent even with full mechanization.

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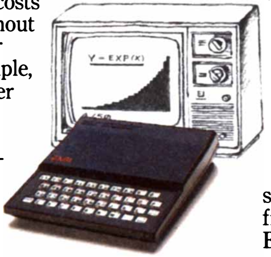

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THE AMATEUR SCIENTIST

When different powders are shaken, they seem to have lives of their own

by Jearl Walker

Mixing a brown powder (Nestea) and an orange one (Tang) in order to prepare a drink called Russian tea, Geoffrey Bate of the Verbatim Corporation in Sunnyvale, Calif., noticed something strange. Although he shook the powders vigorously, they would not mix uniformly. Islands of orange persisted in the pool of brown. Why so? One answer that comes to mind is that an electrostatic separation arises because the grains of powder acquire a charge when they are shaken. Another answer is that the grains of one powder may be slightly smaller than the grains of the other so that they tend to settle differently.

Bate took the matter up with A. D. Moore of the University of Michigan, who among other things is an expert on electrostatics. He said that any electric charge created by the shaking would be too weak to separate such large aggregations of powder. Moreover, an electrostatic separation would be unlikely to form neat piles. Moore concluded that the separation must arise because of a difference in the mechanical properties of the grains.

Putting the powders in a clear beaker, which enabled me to see what was happening at the bottom surface as well as the top one, I did a bit of exploring. With about half a centimeter of Nestea in the beaker I began adding teaspoons of Tang. The Tang remained on top of the Nestea until I gently shook the beaker. With each shake a certain amount of Tang sank into the Nestea. If there was only a little Tang, it soon disappeared. When the amount of Tang began to build up, each shake sank some of the freshly added powder and also exposed islands of what I had put in earlier.

Through the bottom of the beaker I could see the size of the orange area increase as I shook in more Tang. Apparently the powder was migrating to the bottom of the beaker. If I shook the beaker vigorously or even just tilted it a bit, pockets of the sunken Tang were exposed on the top surface. Since the grains of Tang were noticeably smaller than the grains of Nestea, it seemed evident that shaking made individual grains of Tang gradually fall between grains of Nestea.

As a further test I poured everything into a mortar and ground the mixture to a more uniform grain size with a pestle. Returning the powders to the beaker and shaking it, I found no islands of color. The powders mixed evenly because the grains were fairly uniform in size.

To make sure that the islands in the original mixture did not result from some peculiarity in my method of shaking I rigged an audio oscillator to drive a loudspeaker that would shake the powders in a consistent way. The signal from the oscillator was fed through an amplifier and then to the speaker, which was on a table and pointed upward. To the top of the speaker I firmly taped the bottom half of a metal container made to hold motion-picture film. I poured in a small pile of Nestea and over it a layer of Tang. With the oscillator generating a sinusoidal signal at a frequency of 64 hertz I gradually increased the amplitude of the amplifier until the powder began to move. The Tang almost immediately sank into the Nestea.

Grains isolated from the main pile vibrated vigorously and gradually moved to the rim of the container, where the vibration set up by the speaker was at a minimum. This motion was easy to understand. The vertical oscillations of the container tossed the grains upward and slightly to the side. Eventually the center of the plate, where the oscillation was at its most vigorous, had tossed away all its grains. They naturally collected in the area where the oscillation was weakest.

When the entire plate was vibrating only feebly, the pile of powder barely moved. With a somewhat stronger vibration it began to migrate as a body toward the rim. At the maximum vibration the pile disintegrated into individual grains that migrated to the rim.

The tendency of the pile to migrate intact when the vibration was of medium intensity surprised me until I realized the weight of the pile reduced the vibration in that area. Instead of being shaken into individual grains the pile was lifted as a whole. The greater strength of the vibration near the center of the container gradually moved the pile toward the rim.

My arrangement for making the powders vibrate is based on a classic demonstration first given by Ernst F. F. Chladni in 1787. He showed that when a flat plate vibrates, grains of sand sprinkled on it gradually collect at nodes, that is, places with little or no vibration. The patterns, which are now called Chladni patterns, reveal the vibrational characteristics of the plate by marking the nodes. The absence of sand (or powder) shows the antinodes, where the vibration is strongest.

When Chladni replaced his sand with a finer material such as lycopodium powder, he discovered that vibration moved the powder to the antinodes. If he put both sand and lycopodium powder on the plate and set up vibrations, the sand went one way and the powder went the other. Why do large grains shift to the nodes and smaller ones to the antinodes? The classic explanation is that gentle currents of air above the vibrating plate catch the fine powder once it is airborne and gradually carry it to the antinodes. I shall return to this point.

When I went on to see how Nestea and Tang compared with sand on my vibrating-plate apparatus, I encountered several oddities. The first appeared when I poured a pile of Tang on the plate in order to examine how it was affected by changes in the amplitude of vibration. As I turned up the amplitude the pile suddenly pulled in at the base and rose at the top. Individual grains came loose from the top and rolled down the sides. It looked to me as though they reentered the pile at the bottom.

I was astounded. An inert pile of orange powder had become animated. The Tang was circulating, apparently moving along the bottom of the pile toward the center, then rising to the top and finally rolling down the sides to begin the circuit again.

To follow the internal circulation I added a bit of purple Tang as a tracer. Piling the purple powder at the center of the plate and covering the pile with a larger amount of orange powder, I turned up the vibrational amplitude past the point at which internal circulation could be expected. Soon purple grains began to emerge from the top of the pile, near the center; they rolled down the sides of the pile and slowly disappeared into the base.

Trying lycopodium powder on my apparatus (baking powder would do), I again found a threshold above which the pile began to shrink at the base and rise at the center. The internal circulation looked livelier than it had with Tang. I tested the circulation by burying a few grains of purple Tang near the top of the pile. Again they worked their way to the

From 0 to 55,134 feet in exactly 1 hour 9 minutes and 42 seconds.

Julian Nott makes final pre-flight checks.

Nothing inspires a world record holder more than the capture of his world record.

In 1979, it happened to Julian Nott.

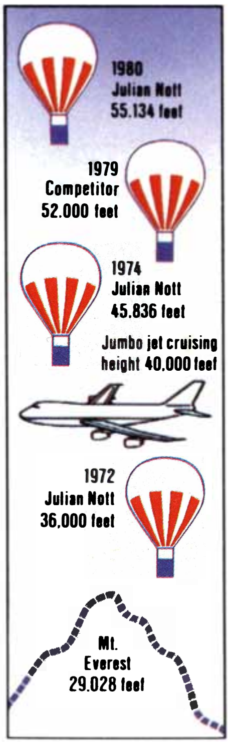
A competitor soared to 52,000 feet in a hot air balloon, exceeding Nott's 1974 record by more than 6,000 feet.

But Julian Nott refused to accept defeat.

Working with a team of dedicated experts, he spent 13 months meticulously planning to regain the record.

If he was to succeed, he would have to pilot his balloon into the top ten percent of the atmosphere. A barometric desert where freezing temperatures, lack of oxygen and virtually non-existent air pressure pose a constant threat to both man and machine.

Every piece of equipment for the ascent was chosen with agonizing attention to detail.



The record since 1972.

The most advanced technology and materials were incorporated.

For example, the pressurized cabin was constructed of the very latest composite plastic, effecting a weight saving of nearly 80 percent over conventional materials.

One vital piece of Julian Nott's equipment, however, remained unchanged from his 1974 ascent.

His watch. A Rolex Oyster. "It came under the same close scrutiny as everything else," remarked Julian, "but, personal preferences aside, its inclusion was never really in doubt."

In 1980, in the early hours of a late October morning, in Denver, Julian Nott and his hot air balloon *Innovation* began the record-breaking attempt.

Using his Rolex Oyster to enable him to always match the computer-designated optimum rate of climb, he rose to a height of 55,134 feet. A new world record.

The world's top balloonists are now turning their attentions to the circumnavigation of the earth.

Julian Nott is one of them.

"Of course, choice of equipment will be crucial for this trip too," he says. "But I'll be very surprised if the first watch to go around the world by balloon isn't a Rolex." He smiles. "Even if it's not mine."

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top of the pile and fell down the sides.

If I made a pile of lycopodium powder vibrate mildly, patterns appeared on top of it. Complex waves formed there and moved down the pile. They appeared to be moving slower than the individual grains that rolled down the sides. Sometimes I could make out what happened as a ridge went down the sides. Falling powder built up the ridge until it was too heavy for the powder lower down the slope to support it. Then the lower powder slid down en masse for a short distance, like an avalanche, and the ridge was reinstated there. This sequence continued until the ridge reached the base of the pile.

Occasionally I was able to create stationary patterns on the pile. Lines running from the top to the base appeared to be formed of powder constantly sliding down. Between them were depressed areas where little movement of powder was visible. Sometimes individual waves traveled up the sides of the pile. This remarkable motion depended on careful adjustment of the vibrational amplitude. A slight increase beyond that level of vibration sent waves of small avalanches down the sides.

I touched the top of a circulating pile of lycopodium powder lightly with the edge of a spoon. Little vibration could be felt, which suggested that the pile was loosely structured close to the top. With a pile of Tang I felt considerably more vibration. The pile was much firmer to the touch but was still loosely structured near the top.

Working again with Tang on top of Nestea, I found that vibration made the former sink into the latter, but I also saw that the internal circulation soon caused grains of Nestea to emerge from the top of the pile. The larger grains usually shook erratically and then fell a slight distance down the sides, where the process was repeated. The large grains that reached the base became separated from the pile; only the finer ones could reenter. Since the grains of Nestea were typically larger than the grains of Tang, a slight segregation of the powders developed at the base of the pile.

I tried blowing gently down on the powder, thinking it would spread out uniformly toward the rim of the container. Instead I saw a bare region in the center and then bands of color: orange and then a separate brown ring that

Islands of Tang in a pool of Nestea


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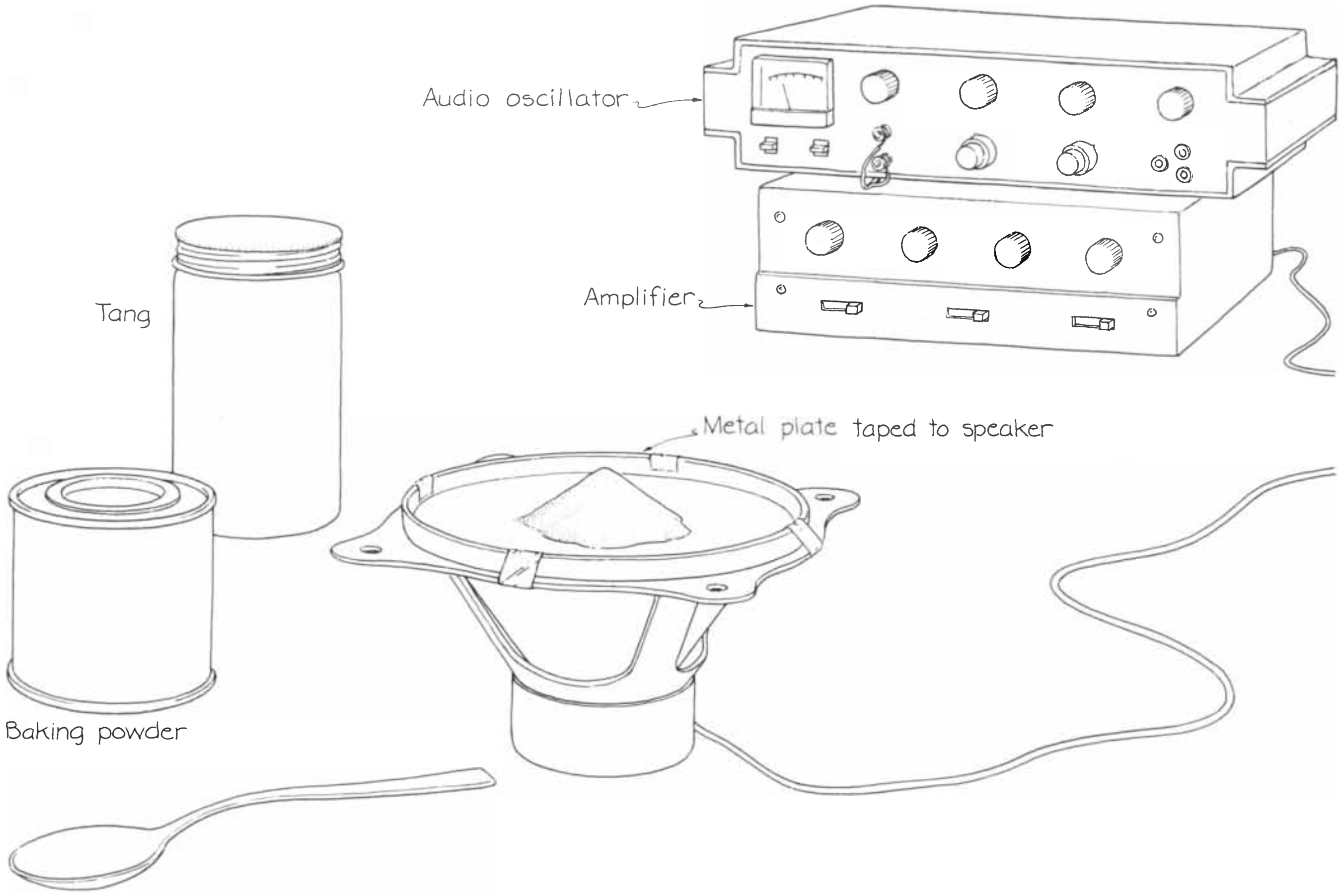


An arrangement for delivering a consistent vibrational force to two powders

seemed to be slightly higher. Apparently the particles of Nestea were being bounced higher than the particles of Tang, and my breath carried them farther from the center.

With powder spread fairly uniformly in the container I stepped up the level of vibration, largely just to see the grains dance. To my surprise I reached a threshold where small mounds of fine powder rose and began migrating on the plate like amoebas, often fusing when they met and occasionally fissioning. At a slightly lower level of vibration they dropped in place; only the larger grains kept bouncing.

I tried the same thing with lycopodium powder and found that many mounds developed. Apparently this is the response of fine powder to intense vibration. The mounds were soft to the touch of a spoon, indicating that they were not solid.

One surprise was still to come. Wanting to see if a barrier on the bottom of the container would alter the flow of powder, I made a hill with modeling clay. I had to clean the metal thoroughly to make sure that the clay would stick to it when the vibrations began. The hill was about one and a half centimeters high and roughly symmetrical; it stood at the center of the plate.

I distributed lycopodium powder around the hill and turned up the vibration to the amplitude that made the powder begin to shake. As before the layers of powder shrank at the base and rose in height. They also began climbing the hill. By increasing the vibrational level more I could make the powder climb to the top of the hill. I could hardly believe my eyes.

Soon so much powder had reached the top that it fell down one side and pooled at the base. It then circulated around the base and eventually began to climb again. Sometimes a notably wide stream climbed on one side and descended on another in a continuous flow. Powder routinely climbed slopes of 45 degrees and occasionally went up even steeper ones.

Is this phenomenon caused by currents of air set up by the vibrating plate and clay? Apparently not. I held the edge of a table knife above a moving stream to block any air current. The knife had no effect unless it actually touched the vibrating particles in the stream.

The powder climbs well at oscillation frequencies below 100 hertz; 60 or thereabouts is best. As I increased the amplitude of the vibration I could see the pile of powder at the base of the hill lift up. A dark line seemed to be visible between the powder and the clay, but it was an illusion resulting from the fact that both powder and clay were oscillating in and out of that region. At the upper end of a climbing stream powder was being thrown upward on the slope until enough had accumulated to start a downward avalanche.

Perhaps the powder climbed the hill only because the vibrations tended to move it toward the center of the plate. To check this possibility I reshaped the clay into two hills adjacent to the center of the container. Powder placed in the valley between them moved away from the center and up each hill.

Next I made a ring of clay surrounding a valley at the center of the plate. I put a mixture of Nestea, Tang and lycopodium powder in the valley. When I increased the vibration until the lycopodium began to move, it mounted the ridge while the other powders stayed in the valley. I had supposed that if the lycopodium could climb hills, the other powders could too at a sufficient amplitude of vibration.

I believe the key difference in the climbing properties of the powders is that lycopodium powder is notably cohesive. The mechanism of climbing appears to be that an upward movement of the vibrating clay throws a few grains at a given spot slightly up the incline. More precisely, the clay surface moves upward, pushing against the layer of powder lying on it and expanding the powder into a less dense concentration. In this condition the layer of powder closest to the surface can slip upward along the bottom of the layer to which it would normally cohere. When the clay descends in the second phase of a vibrational cycle, the rest of the pool of powder falls back on it. The action is repeated with each cycle, a fresh slippage layer being tossed up the slope by each upward vibration. Eventually some of the material tossed upward slides back down over the top of the stream, reaches the lower end and is carried back under the stream. Even in a stream that is standing on a slope too steep to climb, material is always circulating up the slope along the bottom of the stream and down along the top.

The climbing of a slope depends critically on the adhesion to the surface of the grains that are tossed uphill. Cohesion is another important factor. As additional powder is tossed up to a section of the slope already holding grains from an earlier toss some of the fresh powder remains in place because it adheres to the clay and coheres with other grains. Tang and Nestea do not climb because they do not have enough adhesion and cohesion. If I ground one of them into a finer powder, it did climb slopes.

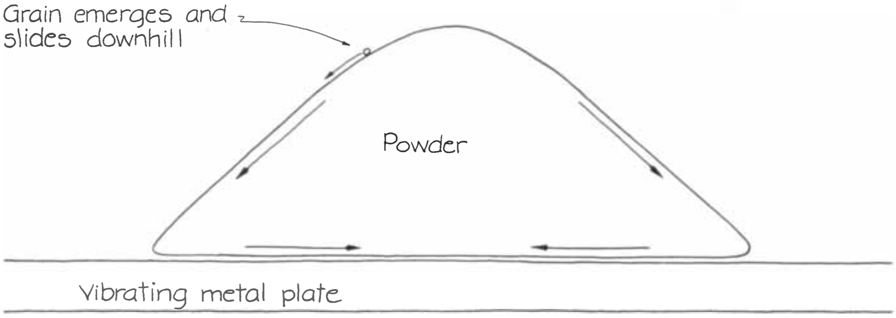
I could make a large grain climb a hill of lycopodium powder. At a mild level of vibration a grain of purple Tang moved up the slope in a series of hops. After each hop it returned to the lycopodium, making a small crater that held it until the next hop.

This last set of observations provided the key that enabled me to understand why individual grains in an oscillating pile move toward the center rather than in some other direction. The entire pile is tossed upward simultaneously and uniformly by a vibrating plate. The density of concentration of the grains decreases, becoming least at the surface and greatest at the bottom.

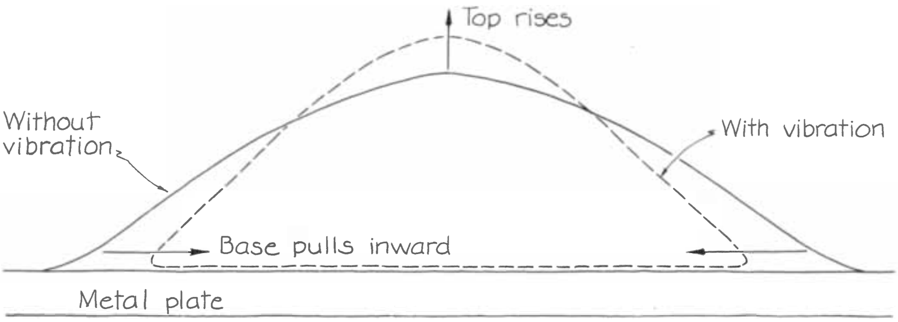
In the bottom illustration at the left a broken line marks the imaginary contour of grains at a particular concentration. Above the boundary the concentration is lower, below the boundary it is higher. Consider a grain just above the boundary. In an upward movement of the plate the grain is tossed slightly up the slope of the boundary. In the next part of the cycle the grain and the pile come down again. One might expect the grain to slide down the boundary at least as far as it had moved up, but friction with other grains moderates the slide. The grain therefore achieves a net motion up the boundary with each toss.

Each grain in the pile can be regarded as lying on such a boundary. In each upward vibration a grain is moved up the boundary because the concentration of grains is lower above the boundary than it is below it. The net movement of the material in the pile is therefore toward the center and the top.

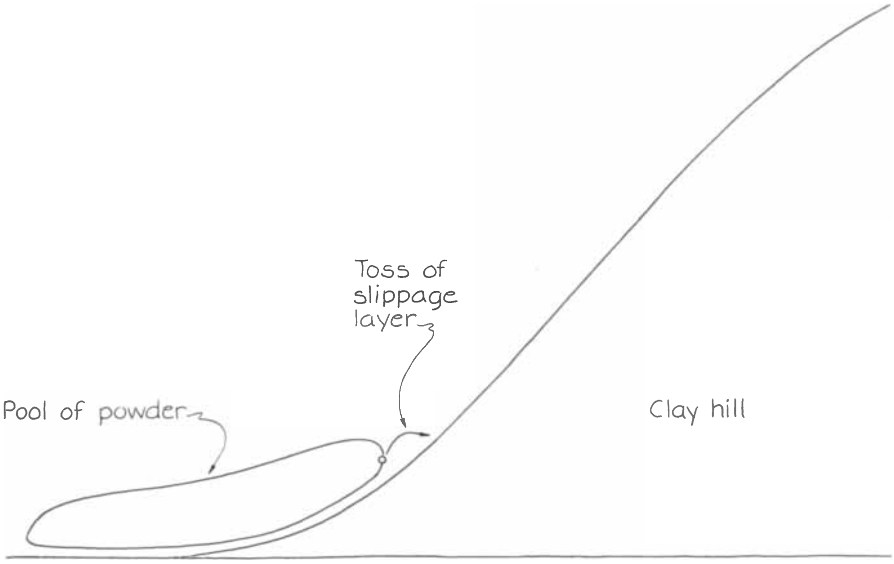
After I had worked out this explana-



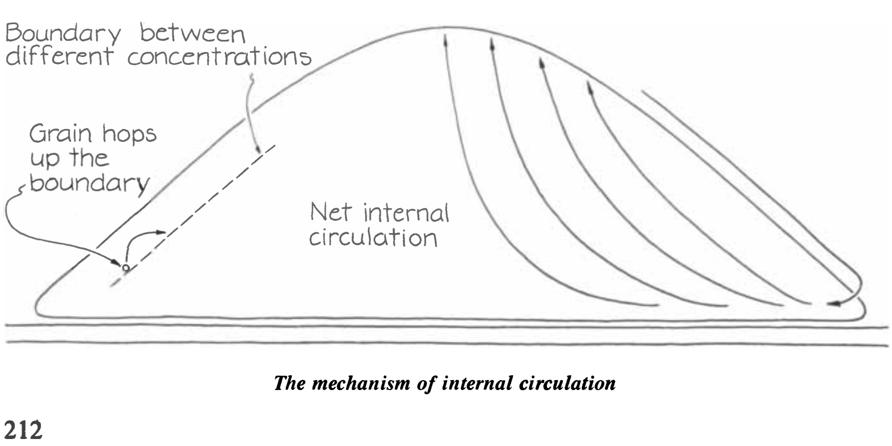
The apparent circulation of powder within the pile



How the profile of a hill of powder changes during vibration



How powder climbs a slope during vibration



The mechanism of internal circulation

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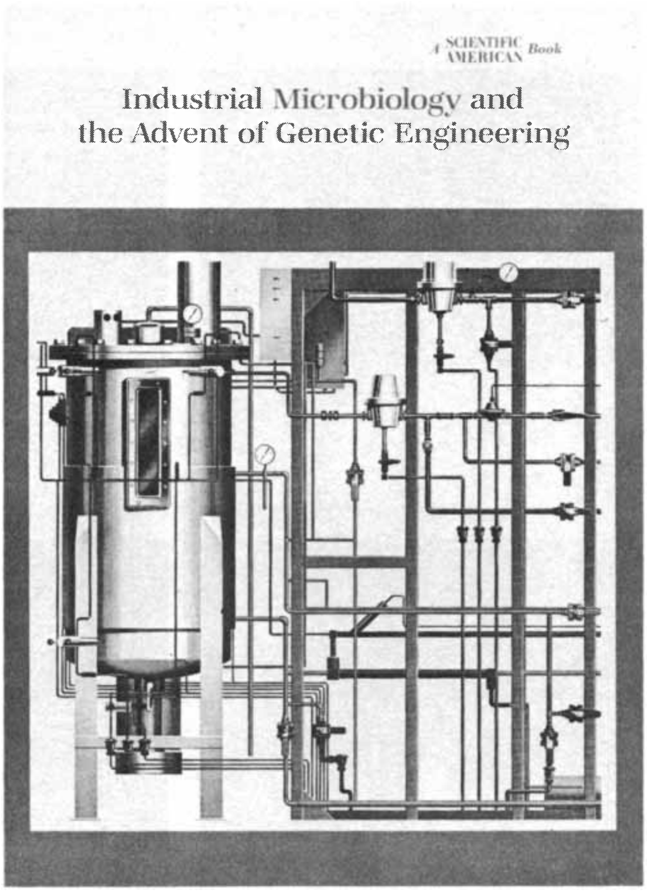

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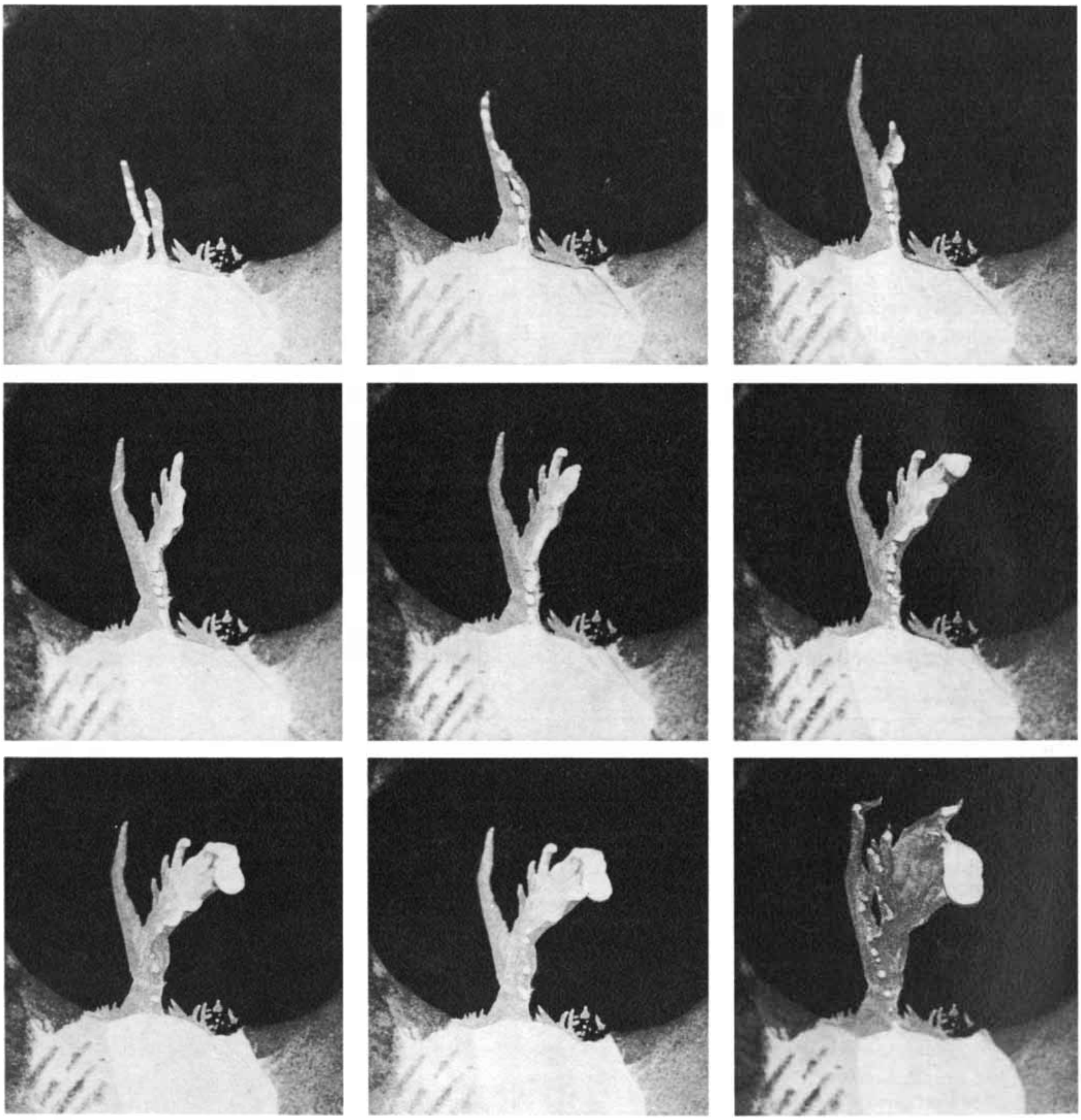
tion I discovered that Michael Faraday, who is best known for his studies of electromagnetism, had published in 1831 a similar set of observations with a different explanation. He noticed that lycopodium powder sprinkled on a vibrating plate gathered into small humps showing an internal circulation. His explanation focused on the flow of air set up by the motion of the plate.

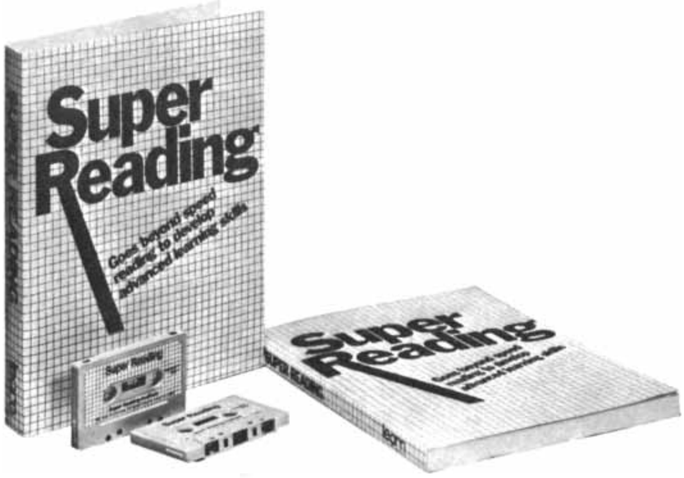
According to this view, an upward vibration lifts the pile and allows air to flow under the base of it, bringing in fresh powder from the perimeter. The amount of material in the pile therefore grows. If air flows under the lifted pile, however, it surely must flow out again as the pile comes down. The model also fails to explain the movement that I observed with tracers (upward in the pile, out at the top and then down a side).

Why is a vibrational frequency of about 60 hertz optimal for internal circulation? The answer is found in work done by R. A. Bagnold, a British petroleum engineer, on the movement of grains. If the plate vibrates too frequently, the lifted pile never gets fully back down before the next vibration. Instead it remains more or less stationary in the air while the plate beats on its bottom surface. On the other hand, the vibrational frequency must be high enough to set the grains in motion.

In April I described certain entoptic phenomena, meaning things that are seen even though they originate within the eye. I said the "floaters" included among the phenomena are due entirely to blood cells released by the retina. Several people who are professionals concerned with vision have written to say that although floaters occasionally originate with blood cells, they are more often bits of the vitreous humor that have come loose and are floating in the watery layer in front of the fovea.



Lycopodium powder climbing a hill of modeling clay that is being vibrated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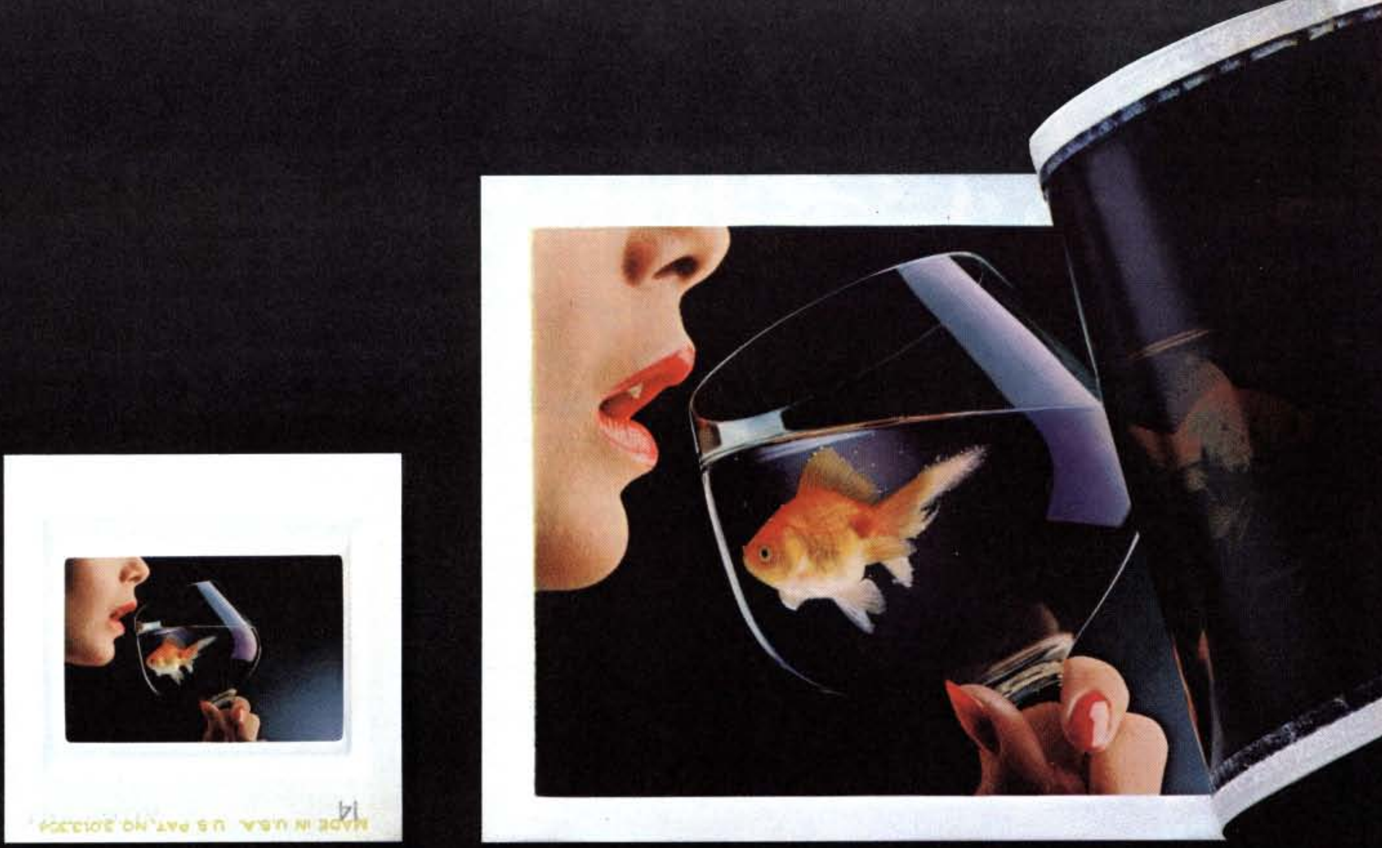


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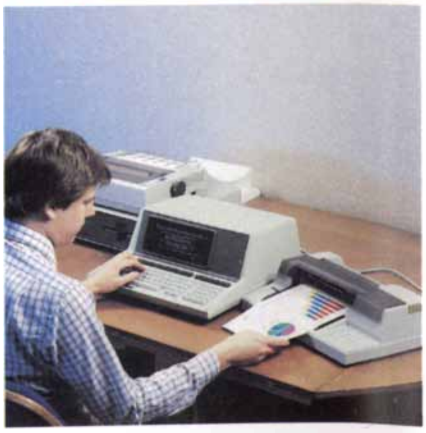

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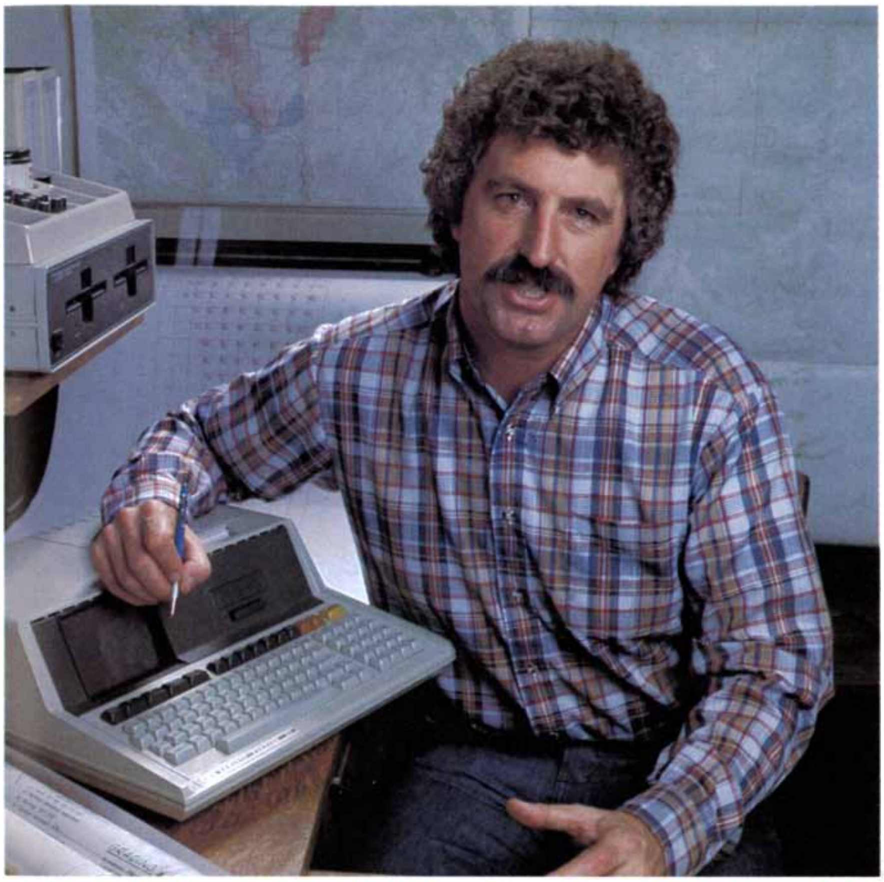

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The HP 125, specifically designed for the business office, offers versatile management software, graphics, and impressive word processing capabilities to users who are not computer specialists. Through instructions displayed on its screen, it guides the user through procedures step by step. As part of a distributed systems network, it can also communicate with large computers. Through its CP/M operating system, the HP 125 offers access to hundreds of software programs.

CP/M is a registered trademark of Digital Research, Inc.

More good reasons to consider a working partnership with HP.

For more information on these personal computer systems, write to A.P. Oliverio, Vice-President, Marketing, Dept. 242, Hewlett-Packard Co., 3000 Hanover St., Palo Alto, CA 94304.

When performance must be measured by results

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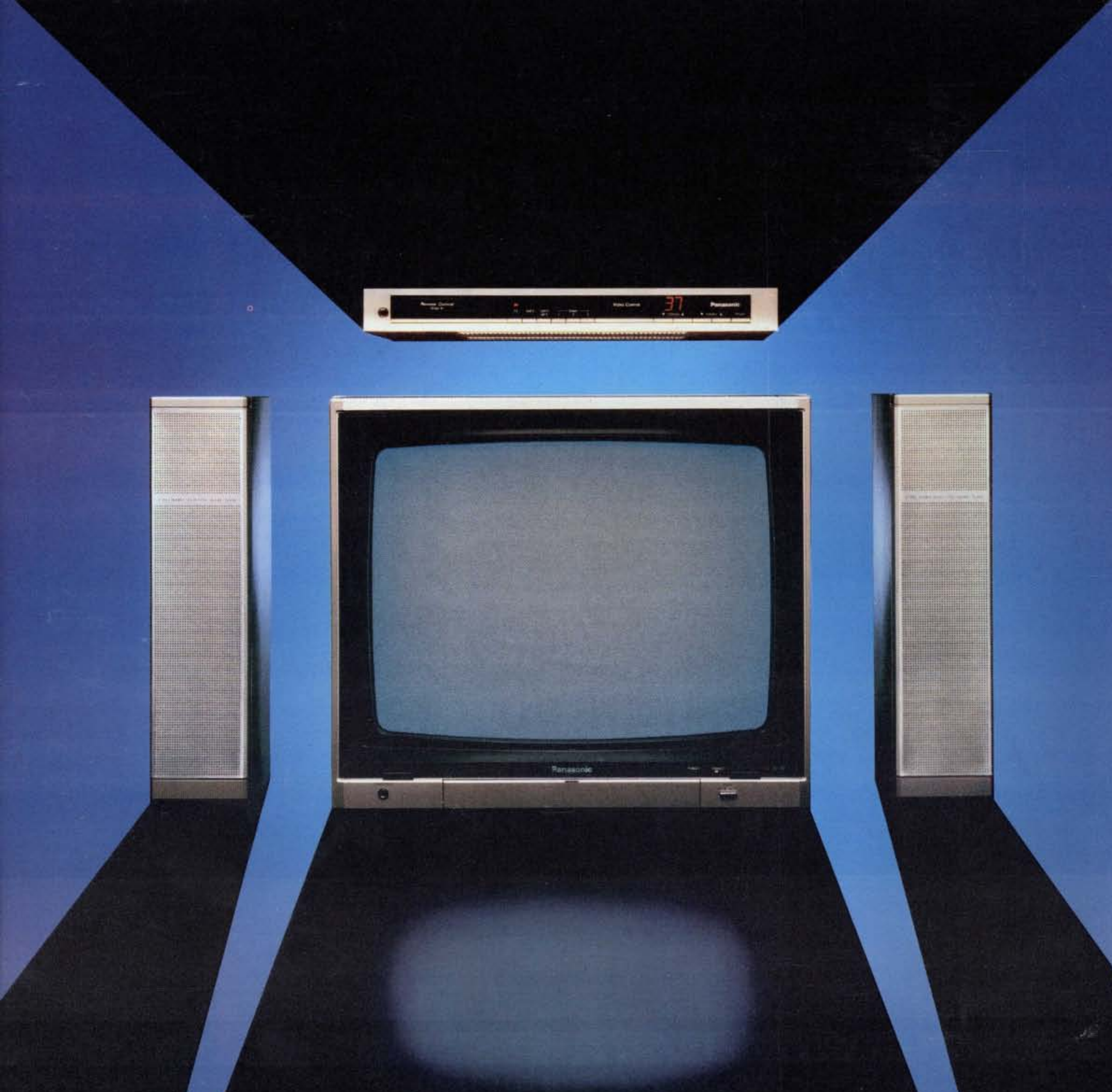

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