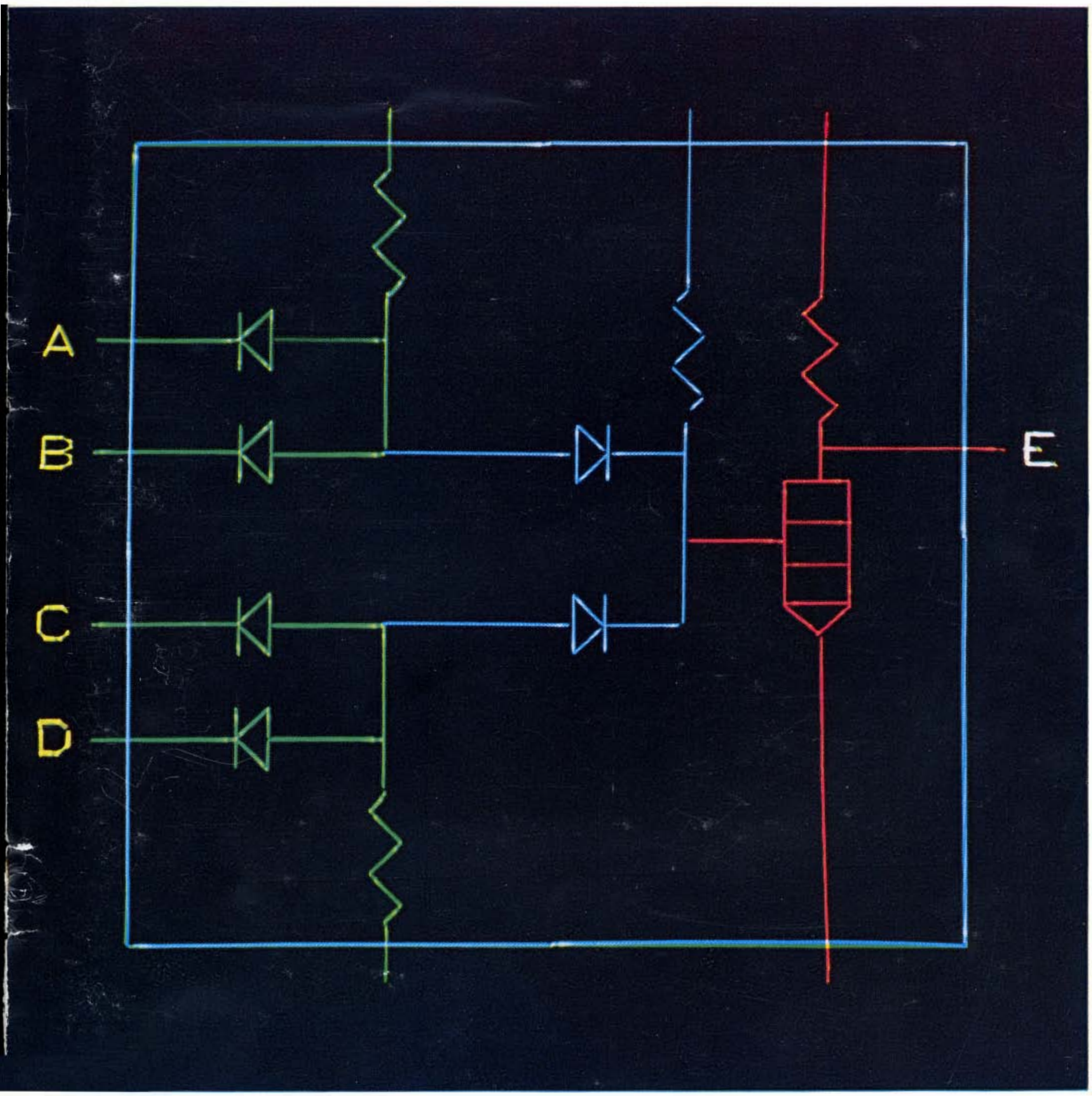
SCIENTIFIC AMERICAN



INFORMATION

SIXTY CENTS

September 1966

How a pharmaceutical company uses First National City Bank in the U. S. and across the world.

IN 31 COUNTRIES...
Structured worldwide pension plan—The company wanted a pension plan to cover 35 key employees—nationals of 31 countries. Through its branches, Citibank a) researched central bank regulations in each country on export of money for pension purposes; b) recommended alternatives where plan was unacceptable; c) recommended short-term investments for pension funds; d) analyzed foreign exchange, tax, dollar availability problems of fund setup, and suggested solutions. This project involved hundreds of Citibank people across the world.

IN THE U.K....
Trustee for foreign pension fund — Citibank's New York-London Trustee Co., Ltd., was appointed trustee and manager of company's pension fund for its 400 employees in the U.K.

FRANCE, ITALY...
Help in foreign acquisitions—Citibank investigated the facilities, managements and prospects of companies the pharmaceutical company wanted to buy, reported on problems of purchasing their stock, assessed capital investment markets in the countries. Bank's branches arranged introductions to managements of potential acquisitions and, in one purchase, helped up to the last minute clearing technical and legal snags.

IN THE U.S....
Recruited foreign financial management—Citibank has an executive "clearing house" for financial experts—supplied candidates for a key job in company's international operation.

AFRICA, ASIA, EUROPE, THE AMERICAS...
Financed expansion of subsidiaries — Citibank funds from short and long term loans, clean credits, trade bill discounts, foreign exchange transactions helped company subsidiaries finance new plants, warehouses, offices, receivables, inventories... in 17 different countries.

WESTERN EUROPE...
Counsel on overseas stock market listing—The company considered listing its stock on one of three European exchanges, asked bank for counsel. Citibank investigated volume and location of foreign stock ownership, anticipated trading volume, cost of listing. The bank analyzed the information, gave the company specific recommendations.

AT COMPANY H.Q....
Worldwide financial know-how — Top Citibank people from New York and senior overseas branch personnel visited company headquarters, counseled company officers on plans and problems, gave them insight into foreign money markets and business conditions.

SOUTH AMERICA
Provided area salesmen with safe, convertible travel funds — FNCB Travelers Checks were made available to the company's South American headquarters at local Citibank branch and automatically charged to company's U.S. account. Salesmen received funds convertible into any currency; company's bookkeeping was simplified.

INDIA...
Located sites for new plant — Citibank's local branch canvassed industrial land within 300 miles of a major city, noting supply of potable water, electricity, labor. The bank later arranged a trip for representative of a local land appraisal firm to company's U.S. headquarters.

NOTE: The company used a wide range of Citibank's important routine services at home and abroad: credit checks; international remittances; personalized letters of introduction; Citibank's Monthly Economic Letter; in-depth analyses of business conditions, etc.

We welcome inquiries about the many services specific to your business, available at First National City Bank.

FIRST NATIONAL CITY BANK
399 PARK AVENUE, NEW YORK, N. Y. 10022 • MEMBER FEDERAL DEPOSIT INSURANCE CORP.

Established 1845 **SCIENTIFIC AMERICAN** September 1966 Volume 215 Number 3

ARTICLES

DEPARTMENTS

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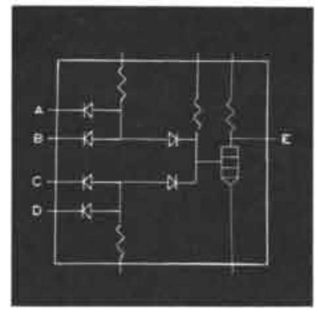

THE COVER

The photograph on the cover symbolizes the theme of this issue of SCIENTIFIC AMERICAN: information, with special reference to how it is processed by computers. The photograph shows a computer-generated display on the screen of an experimental color graphics system developed by the International Business Machines Corporation. The display itself is a diagram of a basic computer circuit; in a sense it can be said that the display represents a computer reflecting on its own nature. The circuit serves the logic function *and/or/invert*. The *and* function is shown in green, the *or* in blue and the *invert* in red. The arrow-like symbols are diodes, the zigzag lines are resistors and the complex structure in red is a transistor. The letters *A*, *B*, *C* and *D* represent logical inputs; the letter *E*, the output.

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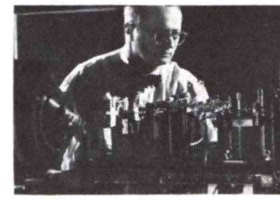
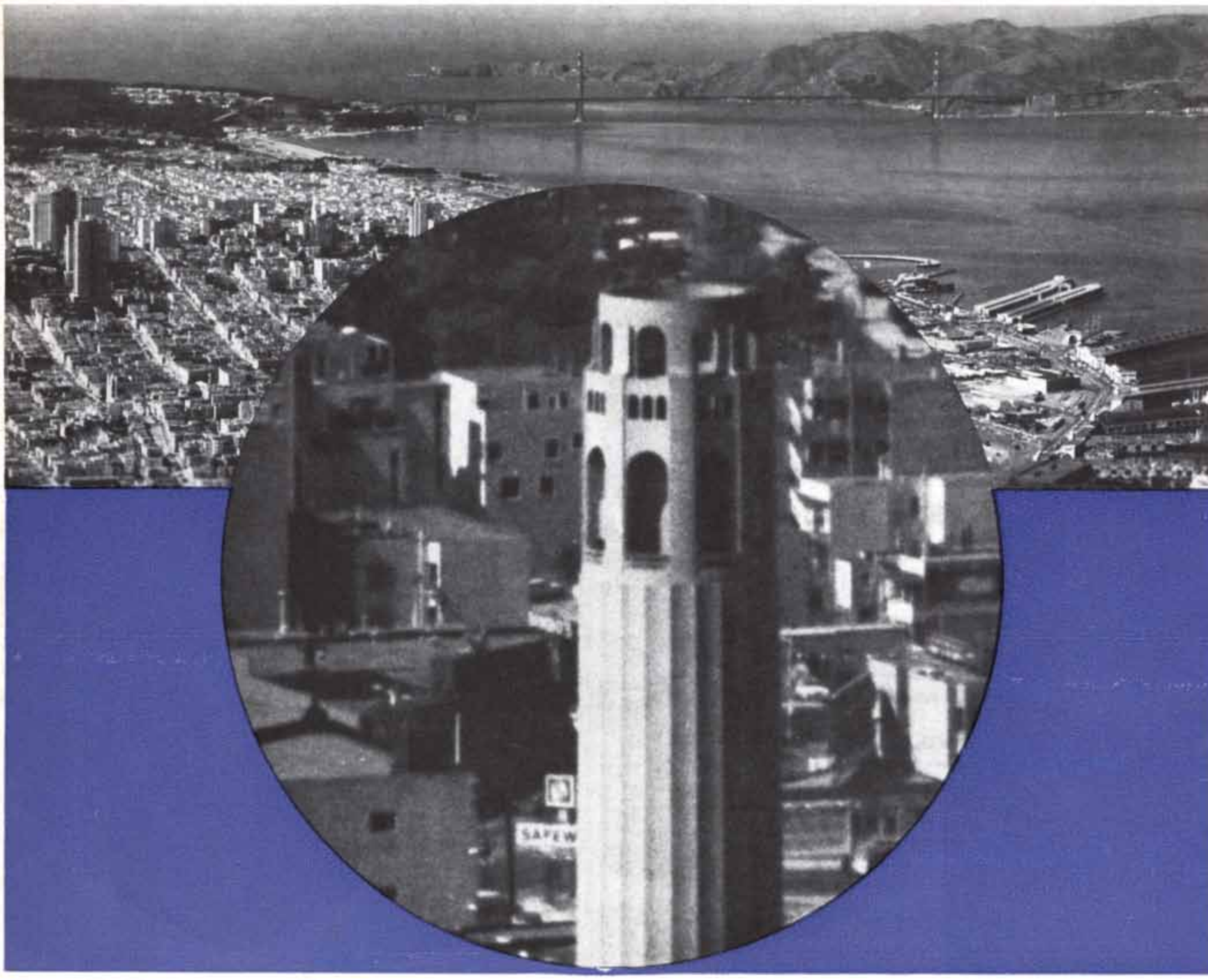




Target of the Knowledge Explosion

He has three times as much to learn as you did. Can he learn it three times faster? Electronic Systems for Education from Sylvania will help.

On top of all his parents had to learn, today's 5-year-old will be bombarded with the staggering amounts of new knowledge continually accumulating.

The Knowledge Explosion is a very real problem for our new generation of students. And to help them cope with it, we must speed the learning process.

Already, Sylvania is working with educators to project completely integrated systems of educational communications. Developing more sophisticated applications. Information "banks" that incorporate libraries on tape, capable of being comprehended at many times the speed of normal speech. Video-taped lecture retrieval. Testing machines that can gauge instantly how a class responds to new information.

Such developments are clearly presaged by our systems at work today. Classroom TV. Mobile TV broadcast and recording studios. And the new all-electronic "Blackboard-by-Wire" remote teaching device that makes possible low-cost, voice-with-graphics transmission to as many as six separate class locations simultaneously.

And every system is custom-designed by Sylvania to meet the demands of a particular problem.

Can schools keep students ahead of the Knowledge Explosion? Yes. And Electronic Systems for Education from Sylvania will help. Sylvania Commercial Electronics, Bedford, Massachusetts.

SYLVANIA

SUBSIDIARY OF
GENERAL TELEPHONE & ELECTRONICS GT&E

COMMERCIAL ELECTRONICS DIVISION

Allen-Bradley has available a complete line of dry reed switching units

Bulletin 1610

BULLETIN 1610L
Magnetically Latched Dry Reed Relays
Latching contacts have permanent magnet bias not strong enough to operate the contacts, but strong enough to hold them in position once they have been operated even if coil power is removed. Relays have coils with separate "latch" and "unlatch" windings. Available with 2, 4, 6, and 8 poles.

BULLETIN 1610
Dry Reed Relays
All A-B dry reed switching units are similar in appearance and construction. Enclosures are identical in height and depth—only the width varies. The dry reed relays consist of individual hermetically sealed contacts, either N.O., N.C., or various combinations of both. A single coil surrounds all the switches in the relay. The steel enclosure completes the magnetic circuit and shields the switches from external fields. Available in four basic enclosure sizes. Standard coil voltages 24 v and 125 v dc.

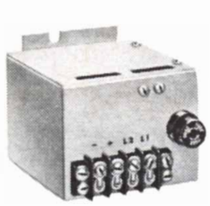
BULLETIN 1614L
Flip-Flop Units
Consist of prewired magnetically latched input and output relays. Output relays have four contacts. Units can be assembled to perform counting functions: binary, binary coded decimal, and decimal counters. No power is required to maintain steady state condition.

BULLETIN 1612L
Shift Register Units
These are self-contained shift register stages consisting of magnetically latched storage and transfer relays. A dual coil surrounds the magnetically biased dry reed switches. Two isolated contacts are available for signal outputs. Can be furnished with various contact arrangements.

BULLETIN 1618
Diode Units
Are assemblies of hermetically sealed high quality silicon diodes conveniently enclosed. The units are internally wired in three ways: separate terminals for each diode, pairs of diodes with a common anode terminal or with a common cathode terminal. Number of diodes: 7 or 13; pairs of diodes: 5 or 9.

BULLETIN 1616
Logic Units
Contain double-wound coils with the windings in opposition. Each winding will cause contact operation when energized alone. Various logic functions can be performed: nor, and exclusive-or, inclusive-or, and comparator. A variety of output contact combinations can be furnished.

Allen-Bradley has many other components and accessories to round out the complete dry reed switching line, such as:



BULLETIN 1690
Power Supply
It furnishes filtered direct current for proper operation of the high speed dry reed devices.

BULLETIN 1691
Resistor-Capacity Network
Provides arc suppression for contact protection when switching inductive loads.

Compact clip-on pilot light units are also available. Readily visible, lights are easy to mount by slipping bracket into a recess at the top of the terminal block.

A-B QUALITY

ALLEN-BRADLEY
Member of NEMA
QUALITY MOTOR CONTROL

1165-2D

SDS announces Sigma 2, a fat-free computer designed for systems.

LETTERS

Sirs:

I should like to make several additions to the very lucid discussion by Sir Edward Bullard of the problem of detecting underground explosions [SCIENTIFIC AMERICAN, July]. Responsibility for research in this area within the Department of Defense rests with Project Vela in the Advanced Research Projects Agency. As part of our current program, a test of the theory of cavity decoupling for a nuclear detonation at a nominal yield of 350 tons is planned for the latter part of 1966. The experiment, referred to by the name "Sterling," will be conducted in the Tatum salt dome near Hattiesburg, Miss., site of the "Salmon" shot in October, 1964. The cavity created during the "Salmon" experiment, 110 feet in diameter at a depth of 2,700 feet, will be used for the "Sterling" event.

The large seismic array in Montana, whose installation is incorrectly attributed to the Atomic Energy Commission in the caption on page 23, is also a part of the program of the Advanced Research Projects Agency. Considerable information about this and similar arrays and on the general subject of the detection of nuclear detonations in all environments can be found in the December 1965 *Proceedings of the Institute of Electrical and Electronics Engineers.*

S. J. LUKASIK

Director for Nuclear Test Detection
Advanced Research Projects Agency
Washington, D.C.

Sirs:

The otherwise excellent discussion of river meanders by Luna B. Leopold and W. B. Langbein [SCIENTIFIC AMERICAN, June] failed to consider important studies by an earlier student of rivers, Mark Twain. Twain of course had no formal background in hydrology, but he made extensive observations from a vantage point 20 to 30 feet above the surface of the river during his apprenticeship as a Mississippi River steamboat pilot after the Civil War. His data were reported in a monograph suitably entitled *Life on the Mississippi,* originally published by H. O. Houghton and Co. in 1874 and 1875. In Chapter 17 he described a riverman's mathematical approach to the calculation of the curves of the river:

"The water cuts the alluvial banks of the 'lower' river into deep horseshoe curves; so deep, indeed, that in some places if you were to get ashore at one extremity of the horseshoe and walk across the neck, half or three quarters of a mile, you could sit down and rest a couple of hours while your steamer was coming around the long elbow, at a speed of ten miles an hour, to take you aboard again."

Twain's attention was caught by one consequence of the meandering flow of rivers that has apparently been overlooked by Leopold and Langbein. He considered the process by which the river in flood from time to time cuts across one of these narrow necks, occasionally with human assistance, and shortens its course appreciably. Twain calculated the results of this process, which he saw in action and historical evidence of which was readily accessible to him:

"In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oölitic Silurian Period, just a million years ago next November, the Lower Mississippi River was upwards of one

Scientific American, September, 1966; Vol. 215, No. 3. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Martin M. Davidson, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 20 cents.

Microfilm correspondence and orders should be addressed to Department SA, University Microfilms, Ann Arbor, Mich. 48107.

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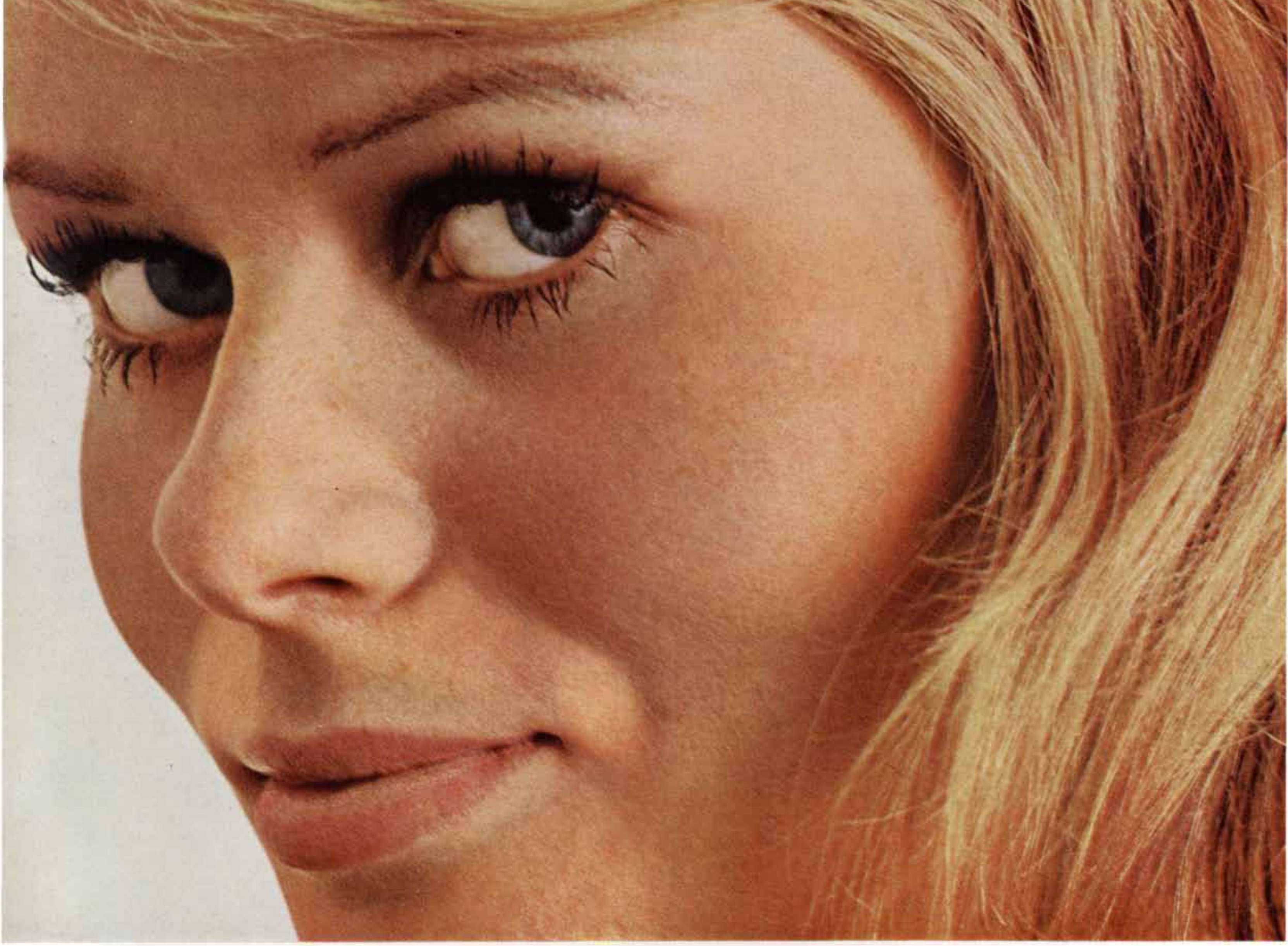


When men take us for granted, it's a compliment.

You men are all alike. You only come to a Hertz counter for one thing: a dependable car. Once you've got it, you take off.

Why shouldn't you? You come for a car, not conversation.

Ah, but let something go wrong. Then you notice us. Then we hear from you. And if we slip-up we deserve it.

Lately, we're happy to say, most of you haven't had much to say to us. That makes our boss very happy. He chalks it up to our good hard work and our great new Fords.

So you can see why a Hertz girl considers it a compliment when a man like you takes us for granted.

No word from you puts in a good word for us—with the boss.

Let Hertz put you in the driver's seat. (Isn't that where you belong?)

HERTZ
RENT A CAR

million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding comfortably along under a single mayor and a mutual board of aldermen. There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact."

I hope Leopold and Langbein will be pleased that in spite of Twain's skeptical attitude toward the science of his day, his descriptions of how to read the river, anticipate bars, find the slack water when steaming upriver and so on are quite in agreement with the data in their recent article.

AVRUM LABE KATCHER, M.D.

Director of Pediatrics
Hunterdon Medical Center
Flemington, N.J.

Sirs:

While agreeing with L. Pearce Williams' main point ["Letters," SCIENTIFIC AMERICAN, June] that "the history of science is a professional and rigorous discipline demanding the same level of skills and scholarship as any other scholarly field," we feel compelled to dissociate ourselves from his strongly implied position that only the professional historian of science can make useful contributions to that field. Such a position would seem to exclude the sympathetic involvement of the professional scientist essential to a meaningful practice of the history of science.

The history of science, it is true, must not deteriorate into a trivial surface examination of the growth of science in terms of its accomplishments. It must also attempt to understand in depth the process of change and the conceptual, methodological and institutional interaction with the larger social and intellectual environment. To assume that this can be accomplished without the help of scientists is unrealistic. Like anything else worth studying, the history of science can be properly viewed from many prospects, each yielding a partial but comprehensible portion of the ever growing totality. These must include the perspective of the practicing scientist. Indeed, many fundamental historical problems can hardly be formulated without the kind of knowledge about science that comes from inside. Scientists can help historians, philosophers and sociologists of science not only to provide and preserve the major documents but also to understand their meaning within the framework of problems worthy of study and analysis.

Professor Williams is entitled to his view that only the professional can write history of science worth reading, but he does not speak for all.

ERWIN N. HIEBERT
ROBERT SIEGFRIED
AARON J. IHDE
W. D. STAHLMAN
VICTOR L. HILTS

Department of the History of Science
University of Wisconsin
Madison, Wis.

Sirs:

I read with interest the letters in your July issue from Frederic E. Holmes and Jack Schubert on the implantation of pennies in the necks of horses. It reminded me of the practice of driving galvanized nails into the trunks of citrus trees growing in zinc-deficient soil. This is said to have arisen from the empirical observation that trees growing close to galvanized-wire fences were more productive than those in the more central parts of the grove. The technique has now been replaced by foliar spraying.

COLIN A. MAWSON, PH.D.

Deep River, Ontario

Sirs:

By way of comment on the letters of Frederic E. Holmes and Jack Schubert, the metal in the coin had very little to do with the reason the coins were placed under the horse's skin; the size was the important thing. The coins were inserted for the treatment of an ailment common to draft horses known as a "sweeny," which was the growing together of the muscle and the skin at a point between the neck and shoulder. In later years, when the large pennies were no longer available, silver quarters, which were about the same size, were used. The movement of the coin kept the skin and muscle separated.

F. LOUIS PATTERSON

Patterson-Shepard, Inc.
Santa Susana, Calif.

SCIENCE/SCOPE

Hughes' new high speed digital computer, the microelectronic HM-4118, was demonstrated recently to the military in Boston, Washington, D.C., and Langley AFB. Built for command and control data processing applications, it will operate in any military environment. The HM-4118 is an 18-bit binary, parallel synchronous system with a 2-microsecond add time, 3.5-microsecond multiply. Average system weighs 230 pounds, occupies 6 cubic feet.

New interwiring techniques developed by Hughes have increased the production rate on the high-density packaging required for large computer systems and reduced the cost per connection. Present semi-automatic interconnection machines can make more than 3,000 terminations per hour. New fully-automatic models will be guided by pre-programmed tape.

A new family of military computers is now in the planning stage at Hughes. Based on a modular concept, family will feature commonality of both hardware and software. It will be developed with existing technology but designed to incorporate new technology as it becomes available. Modules of the very-high-speed, real-time central processor can be grouped to meet the requirements of all types of military systems, from very small to very large.

Complex array microcircuits and high density packaging techniques are features of the HCM-205, new microminiature airborne computer designed by Hughes. It has a 4,096 18-bit word memory expandable to 32,768 words, can perform about 125,000 operations per second, weighs 13.3 lbs. including power supply, and occupies 1/5 of a cubic foot. It will be integrated into a multimode radar data processing system for flight test early next year.

Our expanding advanced computer research programs have created a number of unusual opportunities for design engineers, system architects, senior systems engineers, programming language analysts, and specialists in memory technology. Requirements: accredited degree, 3 to 5 years experience, U. S. citizenship. Please write: Mr. D. A. Bowdoin, Hughes Aircraft Company, Culver City, California. Hughes is an equal opportunity employer.

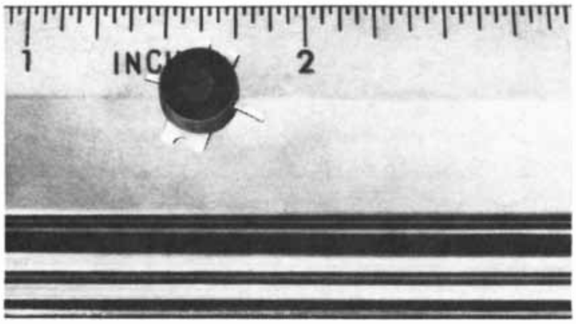
Trend toward larger and larger mass memories is increasing the need for more reliable, less costly, microminiaturized core-drive diode arrays. Hughes' new ultrasonic "Flip-Chip" bonding assembly method allows hundreds of diodes to be connected into mass memory arrays without intraconnection wires. Reliability, yields, production rates, and costs are significantly improved.

An airborne integrated-circuit computer for the F-106/MA-1 weapon system has been successfully demonstrated. It is substantially smaller and lighter than the vacuum-tube computer it will replace -- and 20 times more reliable. It will be the first airborne integrated-circuit computer to be built in production quantities.

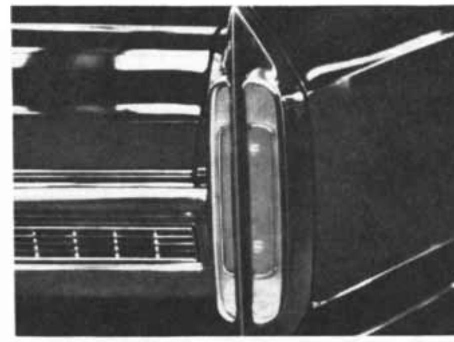
Creating a new world with electronics

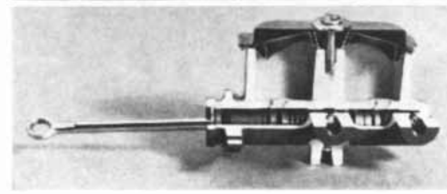
HUGHES

HUGHES AIRCRAFT COMPANY

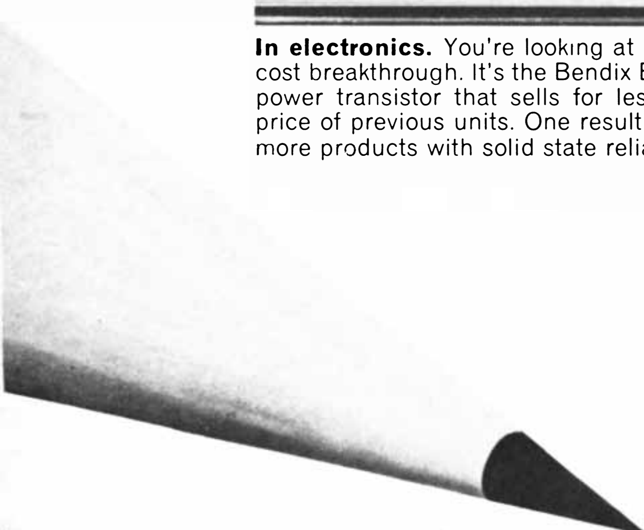


In electronics. You're looking at an exciting new cost breakthrough. It's the Bendix B-5000—a silicon power transistor that sells for less than half the price of previous units. One result: you'll be using more products with solid state reliability.



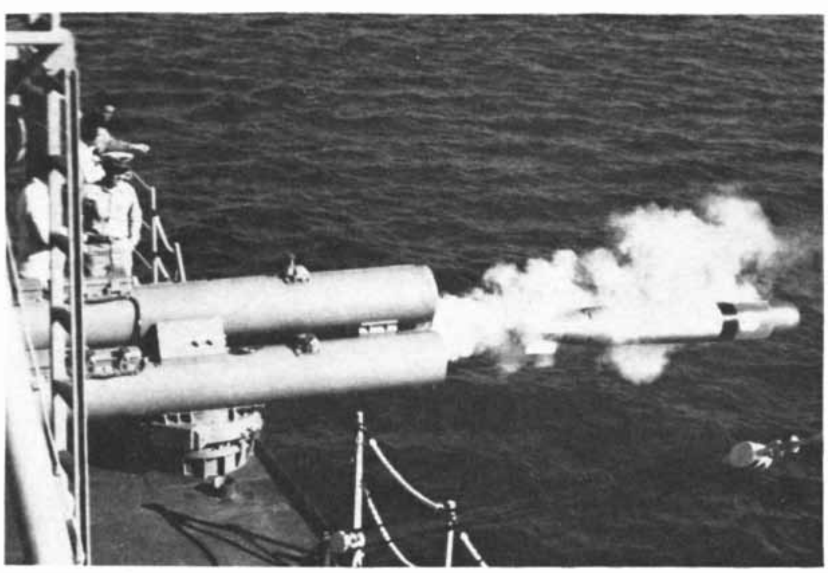


In automobiles. A dual braking system developed by Bendix and auto manufacturers is standard on some '66 cars—still more, including U.S. government vehicles, in '67. The split cylinder (above) provides two independent hydraulic circuits. The system retains front-wheel braking pressure if there's a failure in the circuit to rear wheels—and vice versa.



In aviation. Bendix is a key member of the international team developing an automatic flight control system for the British-French Concorde. Expected to be the first supersonic airliner in commercial service, the Concorde will jet across the Atlantic at twice the speed of sound.

In space. The highly successful performance of Bendix-built inertial guidance platforms on Saturn 1 flights has brought a U.S. manned moon voyage one important step closer to reality. Our platforms are in use on Saturn 1B and scheduled for Apollo lunar flights.



In oceanics. Nerve center of the Mark 46 Mod 1 sub-chasing torpedo is its guidance and control system, developed by Bendix in association with Naval Ordnance Test Station, Pasadena. The Mod 1 can seek out an enemy submarine and then out-run it, out-maneuver it, and destroy it.

THE Bendix CORPORATION

FISHER BUILDING, DETROIT 2, MICHIGAN

WHERE IDEAS UNLOCK THE FUTURE

CREATIVE ENGINEERING FOR: ☐ AUTOMATION ☐ SPACE ☐ MISSILES ☐ AVIATION ☐ AUTOMOTIVE ☐ OCEANICS

To meet your expanding information processing needs

The Burroughs B 6500

A new electronic data processing system with software that is ready right now

The B 6500 will have the kind of multiprocessing ability, dynamic modularity and high through-put per dollar proved in use by the B 5500.

In the B 6500, all these advantages are greatly enhanced by new hardware technology. The result: A system which is ideally suited to engineering/scientific jobs or business applications or a combination of both. A highly advanced time-sharing system which completely obsoletes the rigid time allocations for on-site vs. remote-site work. With the B 6500, numerous jobs—all completely different—can be multiprocessed at the same time, regardless of origin. And all, of course, under full software control.

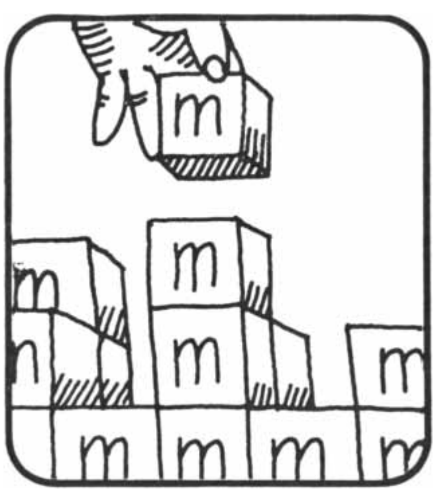
High speed monolithic integrated circuits

The clock rate of the B 6500 is 5 megacycles—an extremely fast speed made possible by the system's monolithic integrated circuitry.

Fast memory speed with thin film

The memory cycle time of the B 6500 is 600 billionths of a second—so fast that it cannot be approached by any computer in its class.

Consider our accelerating success with the unique B 5500 – or better still, see it demonstrated. Now, for requirements that extend beyond this already powerful computer, the new B 6500 implements that same proven software and internal organization by 5 times the processor speed, 7 times the memory speed, up to 3 times the memory capacity, and twice the I/O capability.



Large memory capacity

The B 6500 provides up to 106,496 words of thin film memory. This extensive capacity is available in functionally independent banks.

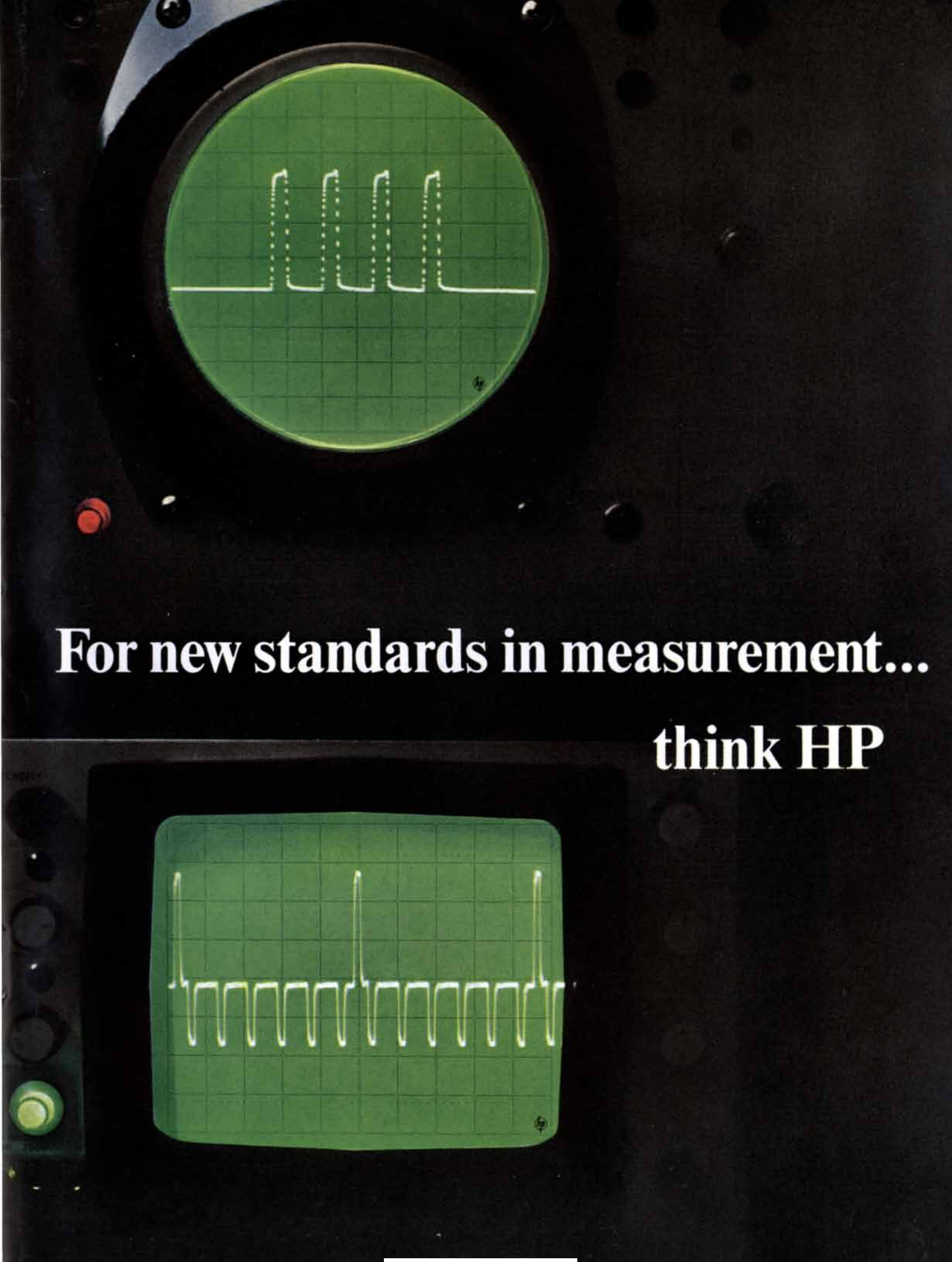
Input/Output Multiplexor

This is a device which provides up to eight high speed input/output operations simultaneous with each other and one or both processors.

We can't show you the hardware today. But we *can* demonstrate the internal organization and proven software: A comprehensive operating system that schedules and controls many jobs at once. Simultaneous COBOL, ALGOL and Fortran compilations. Even a mixture of batch and random access processing plus time-sharing.

Your local Burroughs representative will be glad to arrange such a demonstration or to discuss other Burroughs 500 Systems, ranging from the smaller B 2500 and B 3500 to the giant B 8500. Or write us at Detroit, Michigan 48232.

Burroughs Corporation


For new standards in measurement...
think HP

When Repetitive High-Speed Phenomena Can't Be Observed Directly...

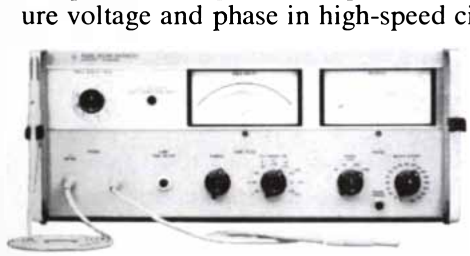
they often can be revealed with gratifying precision by *sampling* them, and observing the sample. At Hewlett-Packard, sampling technology as a measuring finesse is honed to its finest edge. Seven years ago, the HP 185A Sampling Oscilloscope gave information technologists a new wedge into the unknown. With ingenious sampling techniques, practically implemented, this instrument enabled scientists and engineers to convert suspected phenomena (occurring three-quarters of a *billion* times a second) into observable, measurable, useful events. Subsequently, this pioneer instrument was speeded up to observe a billion, then four billion cyclic events per second. With "micro-time" being compressed further in nanosecond (10^{-9} second) and picosecond (10^{-12} second) computer and other circuits, the HP 185 family of oscilloscopes, now superseded, has sired a new generation of faster, smaller, more precise oscilloscopes, and several wholly new instruments which perform measurement feats never before achievable.

What's new in sampling oscilloscopes?

With the development and introduction of new sampling plug-in modules, the 140A and 141A Scopes can now measure to 12.4 GHz (12.4 billion cycles per second), far beyond technology that was new only yesterday. The 140A is a standard plug-in scope. The new 141A is variable-persistence storage scope. The first practical, commerical instrument of this kind, it presents flicker-free views of short transient signals, common to circuitry in information processing systems. Both of these scopes accept the new sampling plug-ins, forming a wide variety of compact, high-performance sampling instruments. Choice may be made of 1, 4 or 12.4 GHz bandwidth. And, for the first time in sampling scopes, delayed sweep (for rapid pinpointing and enlargement of waveform details) is built in. A special-purpose plug-in also gives the versatile 140A and 141A Scopes Time Domain Reflectometer capability. TDR, pioneered by HP, is now an essential to the design and production of micro-miniature circuits, giving fast answers to circuit problems, easily translated into engineering units.

How about sampling voltage and phase?

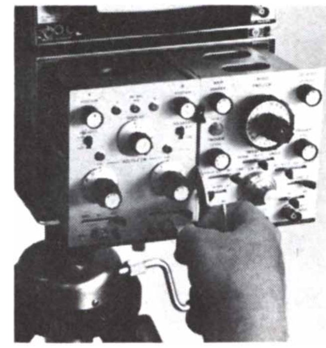
Sampling techniques developed out of oscilloscope design have made possible new instruments to measure voltage and phase in high-speed circuits with unprecedented accuracy and ease. The 8405A Vector Voltmeter simultaneously measures amplitude (voltage) *and* phase relationships between signals, instantly giving the design engineer circuit information previously unavailable, all the way to 1 GHz, for $2500. Another sampling instrument, the HP 3406A RF Voltmeter, provides good sensitivity to 1.5 GHz. It is priced at $650.

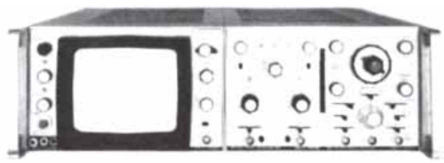


What's the newest, most practical high-performance oscilloscope available?

Possibly the most broadly significant new HP measuring instrument is the 180A Oscilloscope. It's the *only* truly portable scope with the high resolution of "big picture" display (8 x 10 cm). Its bandwidth, in real time, is 50 MHz (50 million cycles per second), and it achieves a new high in sensitivity (5 millivolts/cm) in this broad band. As a plug-in scope, it is versatile, and a hedge against obsolescence.

The 180A offers this unmatched performance in a compact package that weighs only 30 pounds.





It can be used on the bench in any position or mounted on a mobile tripod. As a rack-mounted instrument it is only 5¼ inches high.

1500 standards of measurement...

Hewlett-Packard makes more than 1500 directly compatible measuring instruments: scopes; voltmeters; current, resistance and impedance meters; signal sources, signal and pulse generators; electronic counters; frequency and time standards; microwave instrumentation; amplifiers; power supplies; spectrum analyzers; electronic thermometers; nuclear instruments; diagnostic, patient monitoring and research instruments for medicine; instrumentation for chemical analysis; and instrumentation recorders—strip-chart, oscillographic, X-Y plotters, digital printers, and analog and digital magnetic tape recorders. These instruments interface easily and effectively into unlimited measuring and data acquisition system configurations, without complicated external circuitry or instrument modification.

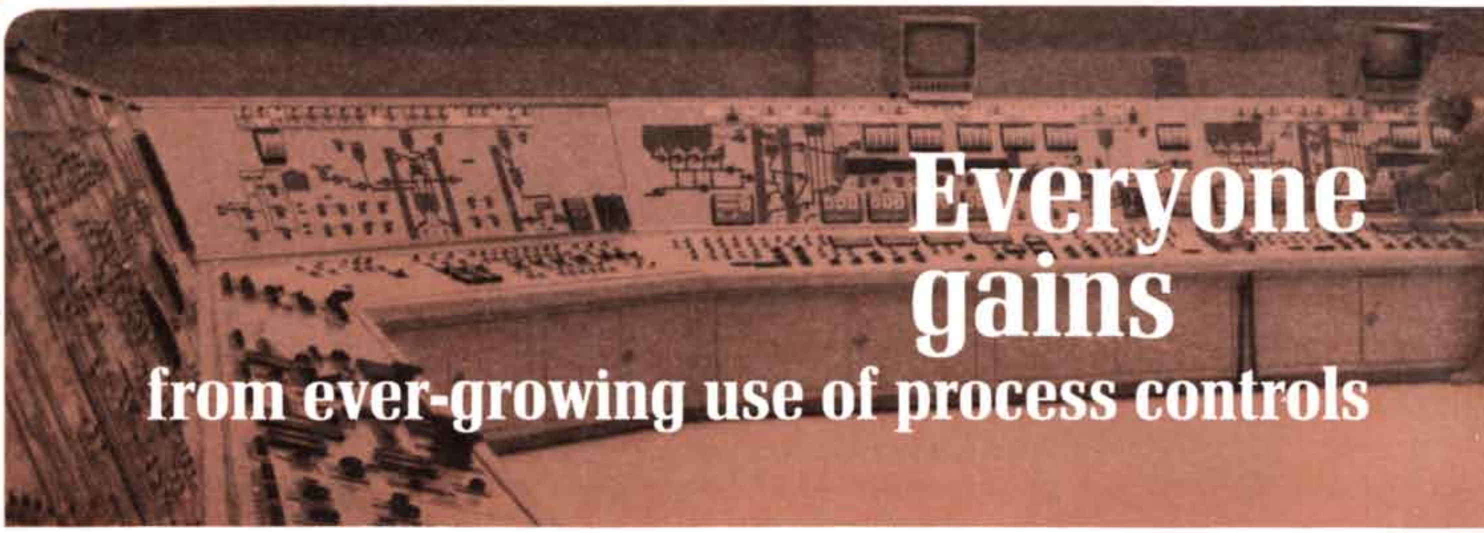
Consider instrument soft-ware...

From instrument design through packaging for shipment, excellence is built in. Nothing is marginal. This is also true of HP's customer support organization. *No customer is marginal.* Throughout the technical world, factory-trained engineers speak all the dialects of measurement: electronic, chemical, medical and nuclear. They provide application assistance, measurement demonstrations, quick delivery, calibration and maintenance service, and a continuing flow of helpful technical information... all on a local basis. Each marketing engineer focuses total HP capability on your measurement needs. This extra measure of quality is built into each of the more than 1500 value-priced HP instruments. HP growth comes through working for you.

For new standards in measurement...think HP

HEWLETT hp PACKARD

measuring instruments for science and industry



Preventing pollution

Effluent from a huge West Coast paper mill pours into the local river. Yet the water is so pure that salmon spawn downstream undisturbed. Foxboro instrumentation is used in this modern waste treatment system and also in the mill's paper-making operations.

In air pollution control, too, Foxboro equipment plays a vital role. At a major steel mill, for example, one of the biggest waste gas cleaners in industry stops tons of dust and smoke particles before they can reach the atmosphere. Foxboro electronic instruments help control it and others like it.

Even more effective pollution-prevention systems are in the offing. Foxboro specialists have developed new analytical instruments, for example, which detect pollutants at levels as low as a few parts per million. These extremely sensitive turbidity, pH, and gas analyzers are already helping to improve the performance of filtration systems, settling tanks, precipitators and other waste treatment devices.

Whipping oil out of sand

Indians once caulked their canoes with tar that oozed from the sandy banks of Canada's Athabasca River. But that seemed to be all that these famous tar sands were good for, until recently. Now, a huge open-pit mining and refining complex is starting to tap a reserve estimated at over 300-billion barrels . . . enough to supply forseeable Canadian and U.S. needs for nearly a century. The refinery will be controlled by more than two thousand Foxboro electronic instruments.

Foxboro controls are used in petroleum and chemical plants all over the world. One of the biggest refineries in Europe, for example, will soon go on-stream under the control of a Foxboro system that provides computers for supervision and optimization as well as Direct Digital Control.

Specialists *in Process and Energy Control*

FOXBORO
REGISTERED TRADEMARK

OFFICES IN PRINCIPAL CITIES. PLANTS IN U.S.A. • CANADA • MEXICO • FRANCE • NETHERLANDS • ENGLAND • JAPAN • AUSTRALIA

Speeding up steelmaking

The Basic Oxygen Furnace makes steel more than five times as fast as open hearths. Foxboro analog instrumentation and digital computers help increase BOF efficiency in many modern mills. In vacuum degassing and continuous casting, too, Foxboro equipment provides accurate, reliable control of critical variables.

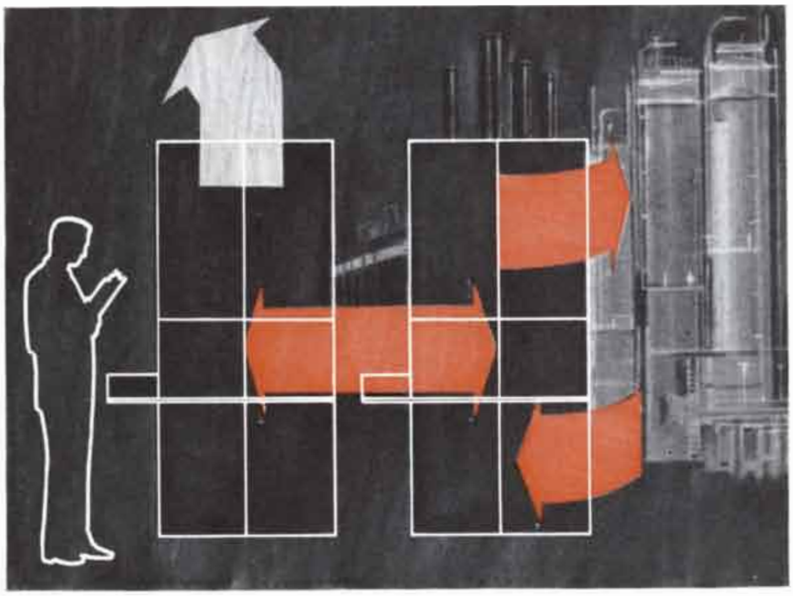
Meanwhile, new control techniques improve the effectiveness of traditional processes. The first blast furnace ever operated under computer control, for example, is regulated by a Foxboro computer system.

Making direct digital control practical

One of the world's most effective computer process control systems is the Foxboro PCP-88. Its compact, multiple computers offer advantages that can't be matched by single-computer systems.

While one computer controls the process, the other can be used for optimization and supervision. If the control computer fails, its twin takes over. System mean-time-between-failures is measured in years, not hours. Do-it-yourself programming enables process engineers to work directly with the supervisory system so that proprietary information stays proprietary.

PCP-88 systems are now being engineered and built for several major chemical and petroleum plants. One of the world's biggest cement plants will be under Direct Digital Control of a PCP-88.



Labor, management, the public at large . . . just about everyone benefits from the advances made by modern control technology. Product quality improves while increased plant efficiency helps keep prices down yet allows fair profits, too. To the furtherance of all these goals, Foxboro brings long experience and the broadest range of control equipment available to the process industries.

A descriptive brochure, "Dimensions of Capability", is yours on request. The Foxboro Company, 659 Norfolk St., Foxboro, Mass., U.S.A.

We build systems that beat the data explosion

You can view an entire strategic situation

Or watch a lunar explorer in action in real-time

Or instantly retrieve one record out of a million

Or find the one part that's acting up in a computer

Or check any customer's credit in an instant

If ever a company was in a position to organize vast quantities of data into meaningful presentations—that company is General Precision.

We take spacecraft television data and produce accurate image material from millions of bits of information. The digital signals relayed to earth from Mars by Mariner IV were converted into pictures by one of our data handling systems. Another system processed the pictures sent by Surveyor I from the moon's surface.

We also build mass memory systems. One huge memory is composed of six 38-inch aluminum discs that can store 200 million bits. We are a leading producer of such digital computer disc files for use with large-scale data processing systems. And smaller memories help supermarkets keep tabs on customer credit... banks on customer balances.

Or, if space is a major problem, we've built some exceptional memory planes—plated-wire memory elements that can be woven like cloth on a machine. Woven thin-film memory planes can be mass-produced at low cost, permit readout in billionths of a second and consume very little power.

As the foremost organization in flight simulation, General Precision makes simulators for training jet pilots and astronauts. Thousands of situations which might face the trainees are realistically simulated on these complex machines. Behind their success is the most sophisticated capability in digital computers. For simulation, we've developed special high-capacity, real-time computers based on integrated circuits.

We've pioneered in automatic diagnostics. Using special programs, computers can diagnose and locate their own faults. Trouble in the most complex system can be localized by the computer operator in a matter of minutes.

Our navigation computers are playing an important part in aircraft and missiles. We've recently developed a highly accurate, low-cost inertial navigation system based on a compact digital computer with core memory and microcircuit logic.

General Precision information handling techniques are making sense out of unwieldy masses of data. They keep track of hurricanes and help control aircraft in flight. They take bulk information from large military zones and reduce it to a form useful for centralized command and control. General Precision has developed high-density film storage and retrieval systems for use with computers. Other systems display information in color to simplify further the viewing of complex data.

Even now, we're looking forward toward the future of organized data systems—of automata, of thinking machines.

General Precision is a primary source of experience for programs involving technological teamwork at highest levels. Our work in aerospace and military fields is well-known. We will be pleased to show how our capabilities fit in with your needs in high-precision electronic areas—data processing, digital information systems including command and control and communications equipment; weapons control; navigation, guidance and control; simulation and radar. General Precision, Inc., a subsidiary of General Precision Equipment Corporation, Tarrytown, New York.

GP GENERAL PRECISION INC

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1916: "The catchword 'preparedness,' which originally meant a state of readiness for a problematical war, has of late come to be applied to an ideal state of national efficiency, not in reference to any particular future event but to the whole future history of our country. The expression was obviously used in this broader sense by the National Academy of Sciences when last April it voted unanimously to offer its services to the President 'in the interest of national preparedness.' The offer met with a hearty response in official quarters and set on foot a train of events that are pregnant with possibilities. After a conference with President Wilson the National Academy appointed an organizing committee, headed by Professor George E. Hale, which has now formulated plans for a National Research Council. These proposals were accepted by the Academy, which authorized its committee to proceed with the organization of the projected council. On July 24th the President also expressed his approval of the plan and announced that the departments of the government had been instructed to cooperate. Lastly, scientific societies, universities and industrial concerns have universally welcomed the scheme and indicated their eagerness to participate. Thus for the first time in the history of this country science, education, industry and the federal government have joined hands in a plan for the promotion of research, as such, without stipulations or preoccupations as to immediate 'practical' returns."

"On the occasion of the sixth annual May Lecture of the Institute of Metals, at a meeting of the Institute in London, Prof. W. H. Bragg, D.Sc., F.R.S., gave an interesting account of the new method of applying the properties of X rays to the study of crystal structure, including the structure of certain metals. The method, it was shown by the professor, results in the determination of the exact relative positions of the atoms of which the crystal is composed. The instrument used is called the X-ray spectrometer. It has no lenses because X rays cannot be refracted, and the rays are invisible, so that in place of the telescope appears a chamber containing gas, which is ionized by the X rays. The resulting electrical effect is observed in an electroscope. If we always use the same X ray, we can compare the spacings between the layers parallel to one after another of the natural faces parallel to the crystal; and in this way we arrive finally at the crystal structure. The instrument is not at all difficult to use, and the observed effects are large and precise, so that it is quite easy to get numerical results. The interpretation is not always quite so easy. One part of it comes readily, viz., the number of molecules to each unit of the pattern of the crystal. The far greater difficulty lies in the determination of the way in which the atoms are arranged in the unit. These data are sufficient, but the interpretation is hard. To understand how it is attempted, and in some cases achieved, is best explained by models."

"The epidemic of infantile paralysis, or poliomyelitis, now ravaging the state and city of New York and extending over a great part of the United States is the most serious in medical history. On September 1st the number of victims in New York State alone had reached 10,000. This cruel disease, which attacks the cerebro-spinal axis, causing death usually by paralysis of the respiratory muscles and crippling the great majority of those who recover, has only lately attracted the attention of medical science. It must, of course, have existed from the earliest times, but it was not described until 1841, when 11 cases occurred in Louisiana. During the past 30 years it has rapidly gained ground, claiming ever larger and larger numbers of helpless children and not a few adults as well, until now it is one of the most dreaded of all diseases. Since it emerged from that obscurity in which for ages its operations have been hidden, poliomyelitis has been the subject of a vast amount of study, but as yet we know neither the manner of its transmission nor any reliable or generally available method of treating it when it is in the acute stage."

Scientific American.

SEPTEMBER, 1866: "M. De Waldeck, an old gentleman more than 100 years of age who served under the first Napoleon, has recently returned to London from Mexico and Peru, where for a long time he employed a staff of Indians in excavating some of the remains of the ruined cities of Central America. He has brought back and exhibited at the Ethnological Society many exquisitely executed drawings and paintings of the grotesque pieces of sculpture dug up under his supervision. Some of the scroll work of the sculptures is very Grecian in its style, and the head of the elephant is frequently reproduced. Mr. Mackie, one of the members of the Ethnological Society, is strongly of the opinion that some of the characters cut upon these remains are of Assyrian origin but is little supported in his views by his colleagues."

"A Mr. Hawkshaw has been engaged for several months in making surveys and calculations with reference to a submarine tunnel under the English Channel to connect France and England. He proposes to sink a shaft on each shore and run adits toward the middle, where he will construct an island as a half-way station and erect a lighthouse upon it. The road will be on an ascending grade from each shore to this central station. It is intended that the tunnel shall be used for steam-locomotive trains exclusively."

"A correspondent, A. J. H., writes on the navigation of the air, insisting that all that is required to make it a permanent success is a proper motor, which will combine the necessary power with the requisite lightness, and says that steam is that motor. He claims to have made a rivetless boiler, which will bear a pressure of from 1,000 to 3,000 pounds per square inch. By thus condensing an enormous power he believes aerostation is an accomplished fact or at least is possible. We cannot agree with him that steam, however much super-heated, is adapted to the purpose. The weight of water, fuel and machinery, to say nothing of the boiler, will be found to be too great, when compared with the mass to be moved in a fluid such as air, to have much margin for available power. What is needed, not only for aerostation but for other purposes, is an entirely new motor which shall dispense with the weight of a boiler with its necessary appurtenances. That a new motor will in time be contrived, without these drawbacks, we have no doubt; but until it is done we have but little faith in economic and successful navigation of the air."

Information: Facts ready for communication and use...by SCM.

The typewriters, calculators, data-processing systems, photocopiers and telecommunications equipment SCM Corporation makes enables business to control and act on the information it has.

The SCM® 7816/330™ data-processing system was developed to give small and medium-sized business automated accounting operations and other essential management controls. Before the 7816/330 arrived, data-processing systems were being engineered on too large a scale to be practical for the small businessman. Now the advantages of a modern unlimited tape-storage computer can be put to work in a small office.

The Smith-Corona® 410™ office electric. The office typewriter is the basic, the most widely used, "information machine." Our Smith-Corona Division makes the finest manual and electric typewriters, both office and portable. There are more Smith-Corona typewriters in offices, schools and homes than any other make.

Kleinschmidt® dataprinters speed information from point to point four times faster than any other. They operate with 80% fewer parts. Kleinschmidt reliability is unmatched and makes this unit a first choice for any communications network.

Coronastat™ copiers make it possible to copy all types of information.

Coronastat copiers make permanent copies of just about anything. And they do it at the lowest possible cost per copy. SCM Corporation makes a full line of Coronastat desk-top and console copiers.

Marchant® calculators include rotary, print-out and electronic units. And each, in its class, is unmatched for speed, capacity and versatility. There's a Marchant calculator to handle every problem!

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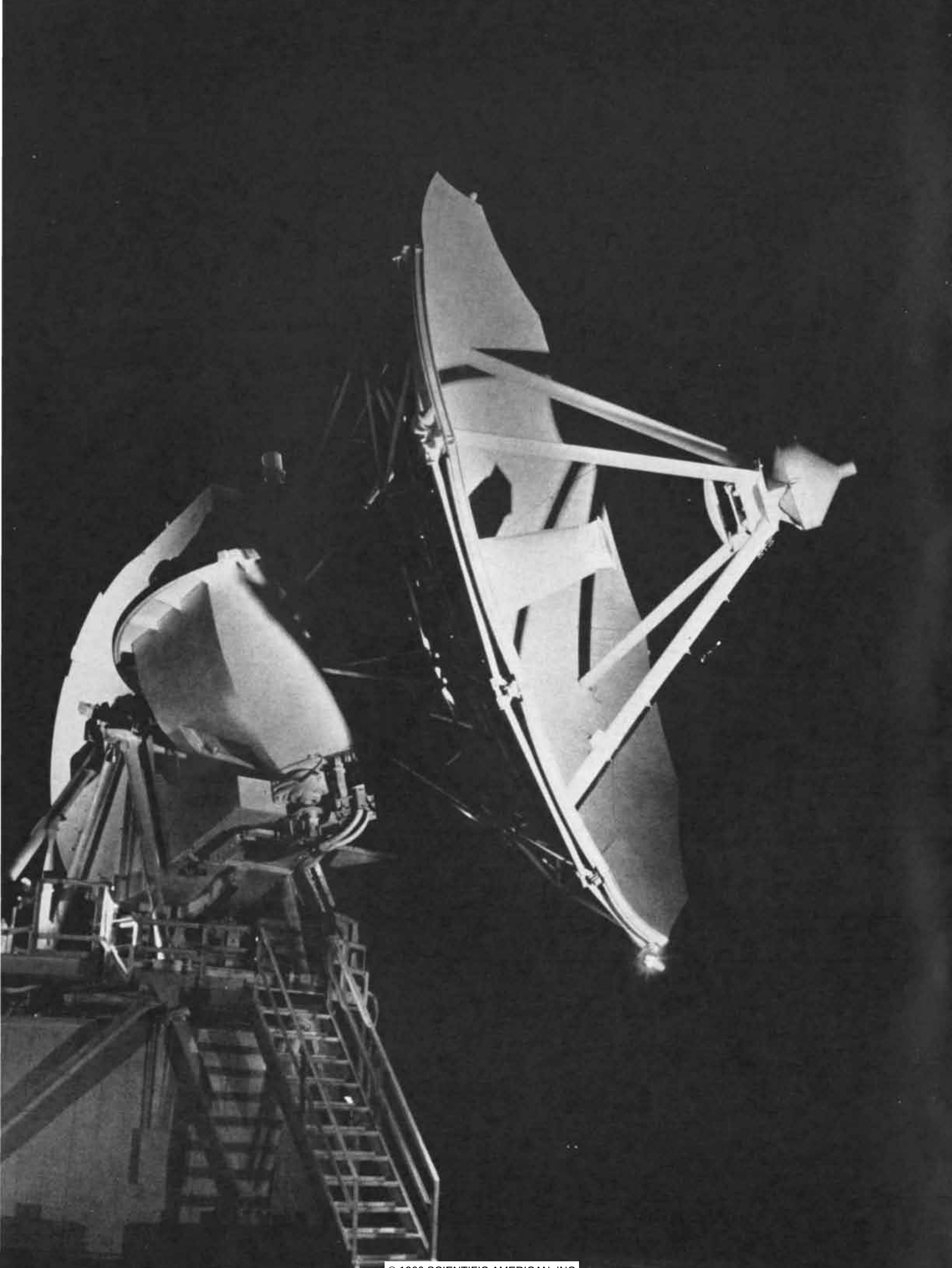
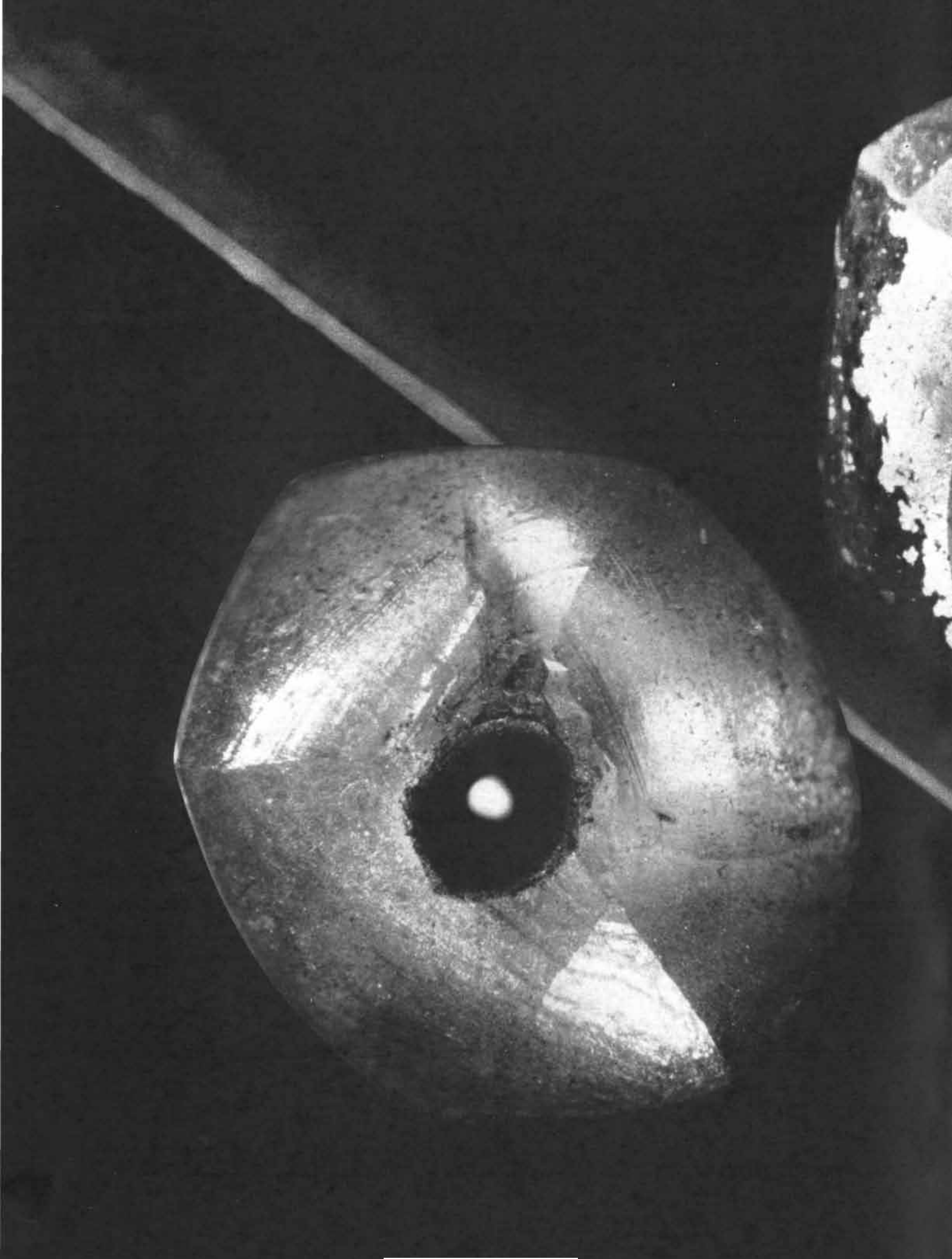




Diamond powder cleans up after laser

Western Electric has harnessed the laser for mass-producing diamond wire-drawing dies. In their Buffalo, N. Y., plant, concentrated light beams are applied to create the initial hole in the die stone—without fracturing or damaging the diamond. These holes, ranging from 12 down to 5 mils, are produced in about two minutes.

However, the holes produced by the laser (left) have a matte finish and require additional sizing. They must be lapped with natural-diamond powder, which is applied with steel shaping pins. These create bell-shaped entrances, and a backward relief in the holes (right).

Final sizing and finishing are accomplished on a polishing machine. Annealed stainless steel wire is charged with natural-diamond compound. The dies reciprocate and revolve, while the tensioned wire remains stationary. This laser-diamond method has increased production efficiency, thus reducing the cost of piercing and reworking diamond dies.

But don't think you have to lap and polish laser apertures to save time and costs with diamonds. Natural and synthetic diamonds are used in grinding wheels, dressing tools and lapping compounds for all sorts of abrasive jobs in metalworking, optics and plastics industries.

Are you frightened by the cost of diamond tools? Don't be. Because if you cut, sharpen, grind or smooth *anything* in your business, you can probably use diamond tools profitably.

Your tool and wheel manufacturer can show you how. Or write to this magazine for more information.

De Beers

World's leading source of natural *and* synthetic diamonds for industry . . . backed by the Diamond Research Laboratory

Shannon, Ireland

THE FULL SPECTRUM OF COMPUTERS FOR SIMULATION-DIGITAL, ANALOG & HYBRID..

ONLY EAI OFFERS ALL THREE.

Simulation, a computer-aided creative design process, places stringent demands on the engineer/scientist and his computer. Our intimate knowledge of this discipline means we can offer assistance in solving the most complex problems of simulation.

For example, we are the only manufacturer of all three basic computer types: analog, hybrid and digital. Our computers are designed to span the entire spectrum of scientific simulation.

We've tailored them with a "hands-on" capability that puts the scientist in the computer loop. The designer, engineer, researcher can handle these powerful computers directly, use intuition in experimenting with the model, apply the lessons of experience at strategic moments in the simulation.

WHICH COMPUTER IS BEST FOR YOU?

Today, EAI manufactures the most powerful—and the most useful—analog computer ever built—the EAI 8800.

We also offer the most advanced medium-scale, real-time digital computer specifically designed for simulation work—the EAI 8400.

Moreover, these two new problem-solving computers were designed to work together in a fully integrated hybrid configuration. We call it the EAI 8900—the most advanced hybrid computing system ever produced.

1 EAI 8800 Analog/Hybrid Computer

EAI® ELECTRONIC ASSOCIATES, INC.
West Long Branch, New Jersey

We also make small computers. The 20-amplifier analog computer sits on the corner of your desk and gives you significant results. It's the TR-20.

We make a larger desktop computer with up to 58 amplifiers and provide high-speed digital logic for advanced hybrid simulations. This is the TR-48/DES-30.

In the medium-sized field, we offer a powerful 10 volt system any research organization would be proud to own. It is the EAI 680 Analog/Hybrid Computer.

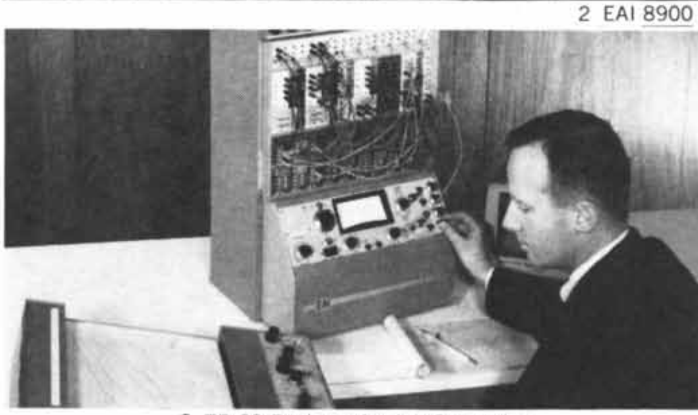
EAI is at the forefront of the field of scientific simulation, both in hardware design and software development. We have the equipment to meet your needs and the experience to help you apply it.

You can depend on us for instruction in the methodology of simulation, as well as assistance with any specific task, whether it is a simulation of a model of the cardio-vascular system, or a tumbling space platform, or an investigation of the dynamic behavior of an interactive social and economic complex.

The user of an EAI computer derives consistent benefit from an ever-growing core of applications experience—a benefit built into the computer from the outset and continued throughout its lifetime.

Let us send you detailed descriptions of any of these computers. You'll see why they are among the very best.

2 EAI 8900 Hybrid Computer



3 TR-20 Desktop Analog Computer

4 EAI 8400 Digital Computer

5 EAI 680 medium-scale Analog/Hybrid Computer

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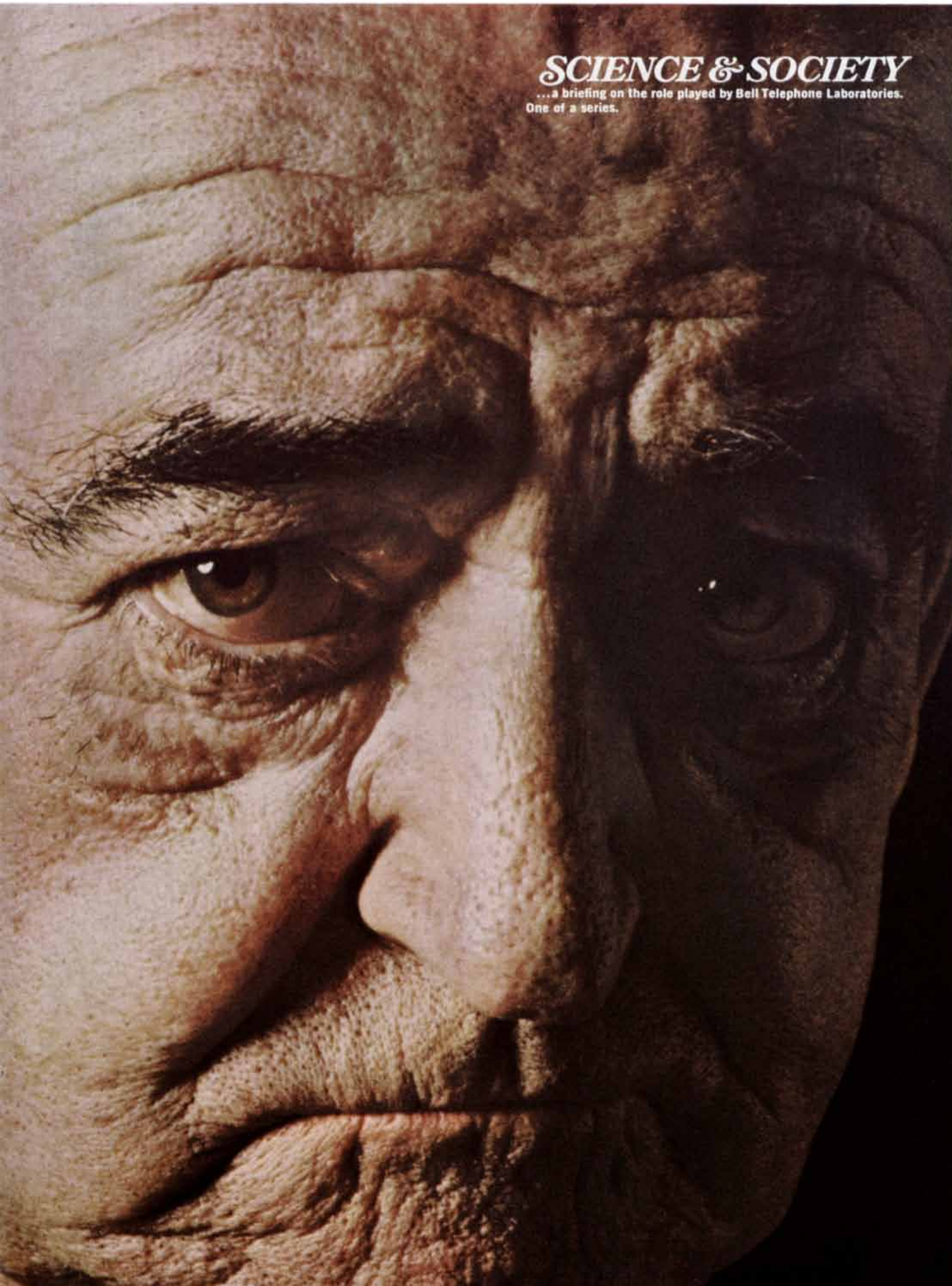
SCIENCE & SOCIETY
...a briefing on the role played by Bell Telephone Laboratories.
One of a series.

Putting superconductivity to work?

RCA knows how

Operating deep down in liquid helium, a few degrees above absolute zero, the RCA experimental memory plane in the dewar is storing and discharging information in the form of persistent circulating supercurrents. In this state of zero resistance, thousands of memory bits are executing "read-write" cycles at pre-selected time intervals—ranging from less than 0.5 microsecond to infinity, or just as long as the plane is held in a superconductive state. At the right, a typical experimental RCA cryoelectric memory plane with 64 binary bits is shown in actual size.

About 25 elements and hundreds of alloys become superconductive—that is, their electrical resistance abruptly vanishes—at temperatures within a few degrees of absolute zero. Below a critical transition temperature (T_c), each of these superconducting elements or alloys develops three fundamental properties: (1) *zero* resistance to dc current, (2) near-perfect diamagnetism to exclude or confine moderate magnetic fields to mere surface penetration and (3) ability to revert to normal electrical resistance in the presence of a sufficiently-strong or critical magnetic field (H_c). Capitalizing on the phenomenon of superconductivity, RCA has put each of these three important properties to work in creating compact, extremely high-speed switching circuits for computers and other applications . . . small-size electromagnets of incredible power . . . parametric microwave amplifiers . . . infrared detectors of exceptional sensitivity.

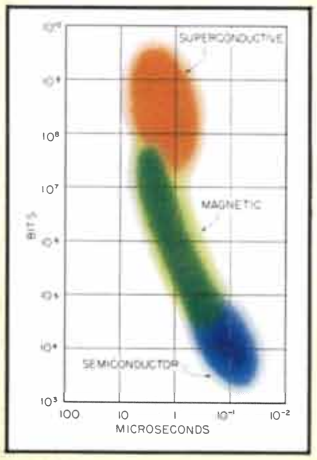

Fig. 1

RCA Superconductive Memories. Superconductors offer far greater potential bit-packing density in computer memory elements than does any current state-of-the-art system . . . and at far lower cost per bit. As shown in Fig. 1 (blue-green areas), present types of magnetic memories have capacity of several million bits per cubic foot at a typical speed of a microsecond.

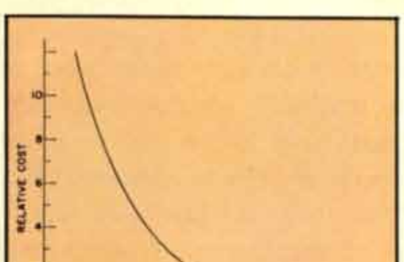

Fig. 2

Superconductive materials—when used in random-access computer memories—give promise of achieving densities in the range of a billion bits per cubic foot and typical speeds from 1 to 10 μs. These superconductive memory elements readily have excellent potential for mass-production techniques that will substantially reduce the initial cost of a computer in terms of a given memory size. Fig. 2 shows the estimated cost of an RCA stack as a function of the number of bits per plane. For the largest memory indicated, the cost of the completed system, including the refrigerator, may be *less than a cent per bit*—substantially below the cost of current memories of comparable size and capabilities.

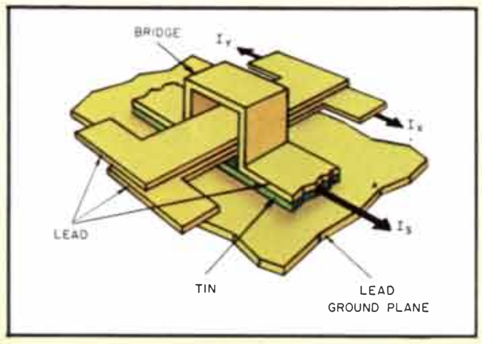

Fig. 3

How Cryoelectric Computer Memories Function. Memories under development at RCA store information in films of superconductive material in the form of a persistent current that continues until disturbed by a magnetic field or a rise in the ambient temperature above the critical point.

Fig. 3 shows a single X-Y junction in a bit-organized RCA cryoelectric memory. Around the junction is a storage loop formed by the lead bridge and the tin strip. The current to be stored, I_s, is applied to the composite lead-tin line.

Coincidence of I_x and I_y drive currents produces a magnetic field strong enough to switch the tin film beneath the junction, forcing I_s over the lead bridge. When the drive pulses are removed, that area of the storage loop again becomes superconductive, and a persistent current remains indefinitely within the loop until it is read out by subsequent drive pulses. Fig. 4 shows the arrangement of address lines, decoders, and storage loops in a bit-organized memory array. These elements are deposited by techniques developed and proved by RCA in the making of integrated circuit modules. Practical cryoelectric memory planes—similar to that shown in the lower right main illustration—might well contain as many as a million bits!

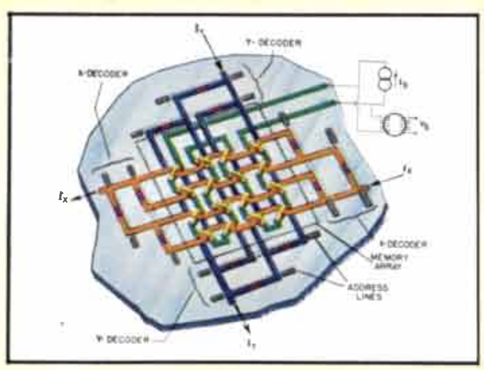

Fig. 4

RCA is experimenting with a 512 x 512 bit plane employing 2-mil drive lines, containing 262,144 bits and requiring a substrate of only 4 square inches including lead-outs . . . a bit-packaging density at least 10 times greater than the best ferrite-core memory planes now available.

Thus, for truly high-capacity, high-speed memories (indicated for use in such applications as an effective strategic missile command system of the future), cryoelectric memories seem to offer the best present potential.

Other Superconductive Materials offer equal potential in terms of economy of space and power, as well as of probable utility. These are the superconductive materials which require a *high* applied field to bring about transition to normal conductivity, such as a niobium-tin (Nb_3Sn) with a transition temperature (T_c) of 18°K and an upper critical field (H_{c2}) that exceeds 220 kilogauss at 4.2°K. These high-energy, high-field materials are well suited for use in large working volume superconductive magnets, combining small overall size and very high magnetic fields.

RCA has developed a process for producing a practical ribbon of superconductive Nb_3Sn material (shown in cross-section in Fig. 5), as well as techniques for winding this ribbon into compact coils which are currently being used to build magnets that will generate fields up to 150 kG. The superconductive material is vapor-deposited on a thin metal support. Below

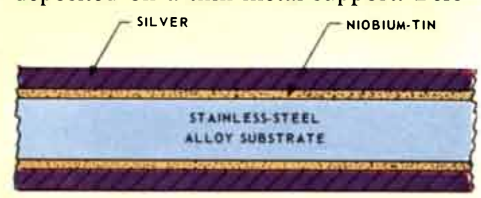

Fig. 5

the critical transition temperature, all current flows through the Nb_3Sn layer; above this T_c, the alloy becomes normally resistive, and current flow switches to the layer of silver overlay. RCA superconductive magnets are already in existence that produce fields which in contrast require enormous-size conventional magnets. These RCA-made magnets can operate from small power supplies or storage batteries and do not need the millions of watts consumed by conventional magnets. In addition, they are only fractions of the weight of conventional magnets of equal magnetic field and working volume.

RCA has the production capacity and engineering knowledge to produce both superconductive materials and magnetic devices to be used for such applications as plasma containment research; bending magnets; beam-focusing devices; bubble chambers; MHD devices, and rotating cryogenic devices (generators and motors).

RCA developments in superconductivity of materials, devices and techniques provide new tools for fields of activity ranging from high-energy physics research to the storage of energy, from work in magnetic space applications to magnetohydrodynamics. Available superconductive products and applications—as well as many others now under study at RCA—take full advantage of the remarkable phenomena unique to superconductivity.

Perhaps the solution to your problem lies in RCA superconductive products—or in the knowledge RCA has gained from its cryoelectric research and development program. Write or telephone us about your specific problems. Address RCA Commercial Engineering, Section I95EC, 415 South Fifth Street, Harrison, New Jersey 07029—(201) 485-3900.

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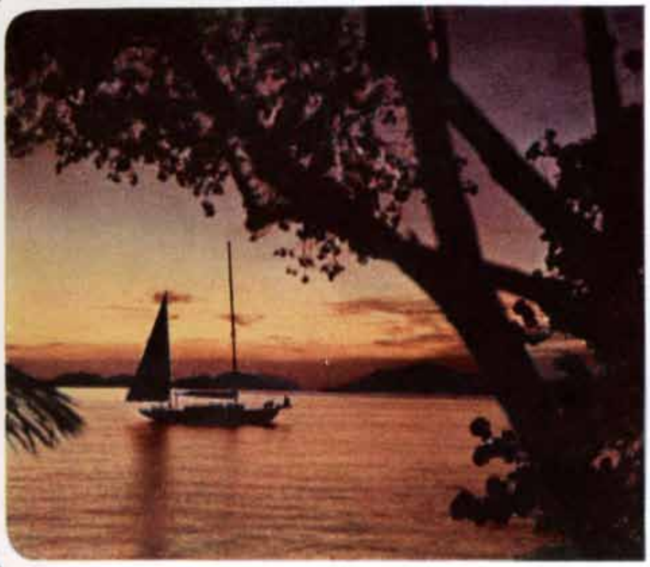

THE AUTHORS

JOHN McCARTHY ("Information") is professor of computer science at Stanford University. A graduate of the California Institute of Technology in 1948, he received a Ph.D. in mathematics at Princeton University in 1951. Thereafter he taught at Princeton, Stanford, Dartmouth College and the Massachusetts Institute of Technology before taking up his present work. McCarthy's particular interests are computer programming languages, the theory of computation and artificial intelligence.

DAVID C. EVANS ("Computer Logic and Memory") is professor of electrical engineering and director of computer science at the University of Utah. He was graduated from that university in 1949 and obtained a Ph.D. in physics there four years later. From 1953 to 1962 he was director of engineering of the Bendix Corporation's computer division. He then spent three years as professor and associate director of the computing system at the University of California at Berkeley before going to the University of Utah. Evans describes his principal interest as "man-machine systems: the development of interactive computing systems for computer-aided problem-solving."

IVAN E. SUTHERLAND ("Computer Inputs and Outputs") has just left the Department of Defense, where for two years he was director of information-processing techniques at the Advanced Research Projects Agency, to become associate professor of electrical engineering at Harvard University. He received a bachelor's degree in electrical engineering from the Carnegie Institute of Technology in 1959, a master's degree from the California Institute of Technology in 1960 and a Ph.D. at the Massachusetts Institute of Technology in 1963. In his doctoral thesis, entitled "Sketchpad," he set forth a program by which a computer could accept drawings directly from a user and help him to make and manipulate them. The concept has attracted wide attention. Sutherland writes: "Computers can store and calculate results from models of the physical world. I am excited by the prospect of being able to manipulate such models easily and observe them with great realism. Hence my work centers on human control of computers through keyboards, buttons, knobs, light pens, sound and so forth and on display of computer information through writing, pictures, sound and whatever else we are able to do."

CHRISTOPHER STRACHEY ("System Analysis and Programming") is leader of the Programming Research Group at the Computing Laboratory of the University of Oxford. He was graduated from the University of Cambridge in 1939 and spent the war years as a physicist working on the design of radar tubes. From 1944 to 1951 he taught in preparatory schools; since then he has been working with computers. "My chief interest," he writes, "is to develop the mathematical foundations of programming and, if possible, to simplify programming (particularly that of large "software" systems) and to make the design of machines more rational."

R. M. FANO and F. J. CORBATÓ ("Time-sharing on Computers") are both at the Massachusetts Institute of Technology. Fano is professor of engineering and of electrical communications; he is also director of Project MAC, an M.I.T. undertaking concerned with research on advanced computer systems. Corbató is professor of electrical engineering and deputy director of the M.I.T. Computation Center. Fano, who was born in Italy and came to the U.S. in 1939, has been at M.I.T. since 1941; he obtained a doctorate in electrical engineering there in 1947. He is the author of a book, *Transmission of Information,* and coauthor of two textbooks. Corbató received a bachelor's degree from the California Institute of Technology in 1950 and a doctorate in physics at M.I.T. in 1956. He has had much to do with the design and development of multiple-access computer systems. In his spare time he enjoys skiing and hiking. The work reported in the article by Fano and Corbató was supported by Project MAC, which is sponsored by the Advanced Research Projects Agency of the Department of Defense under a contract from the Office of Naval Research. The work reported in the articles by Martin Greenberger and Marvin L. Minsky had the same sponsorship.

JOHN R. PIERCE ("The Transmission of Computer Data") is executive director of research in the communications sciences division of the Bell Telephone Laboratories. He joined Bell Laboratories in 1936, the year he received a Ph.D. in electrical engineering at the California Institute of Technology, where he had previously obtained bachelor's and master's degrees. Pierce's chief work has concerned microwave tubes and communication, including communication by means of satellites. He has published books on electron beams, traveling-wave tubes, speech and hearing, information theory and quantum electronics.

ANTHONY G. OETTINGER ("The Uses of Computers in Science") is professor of linguistics and of applied mathematics at Harvard University. Except for the academic year 1951–1952, when he was a Henry fellow at the University of Cambridge, he has been at Harvard since 1947; he obtained a bachelor's degree there in 1951 and a doctorate in 1954. He writes: "I have been at work in the linguistics area for a decade, but for the past two years I have shifted to the problems of the educational use of computers."

STEVEN ANSON COONS ("The Uses of Computers in Technology") is associate professor of mechanical engineering at the Massachusetts Institute of Technology. He has been at M.I.T. since 1948; for eight years before that he was a design engineer with the Chance-Vought Aircraft Division of the United Aircraft Corporation, where he devised mathematical methods for describing the shape of airplane fuselages by computer. During the past six years Coons has been in charge of the computer-aided design group of the design division of the mechanical engineering department at M.I.T. He has written a number of papers on design and the geometry and description of shapes. He is also coauthor of a textbook on graphics.

MARTIN GREENBERGER ("The Uses of Computers in Organizations") is associate professor at the Sloan School of Management at the Massachusetts Institute of Technology. He describes himself as "an applied mathematician by training with growing interests in economics and psychology" and says that his work with computers "sometimes enables me to bring these different affinities together." Greenberger received his bachelor's, master's and doctor's degrees in applied mathematics at Harvard University. Before joining the M.I.T. faculty in 1958 he formed and managed Applied Science Cambridge, a part of the International Business Machines Corporation that cooperated with M.I.T. in

It's a computer world

It seems wherever you go these days you run into a computer.

On campuses, like the University of Omaha, an NCR RMC (Rod Memory Computer) is being installed to maintain a student history data bank, instantaneously storing and making available on CRAM (Card Random Access Memory) cards everything from parking tickets to I. Q. to campus membership to grades. Scheduling classrooms and instructors to make optimum use of facilities. Providing engineering students with on-line Fortran IV inquiry points for quick solutions to mathematical problems far too complex for traditional assignment. It all happens at once. True multi-programming in an on-line and off-line mode.

Secondary schools are using NCR 315 computers to actually teach and subsequently quiz and grade students.

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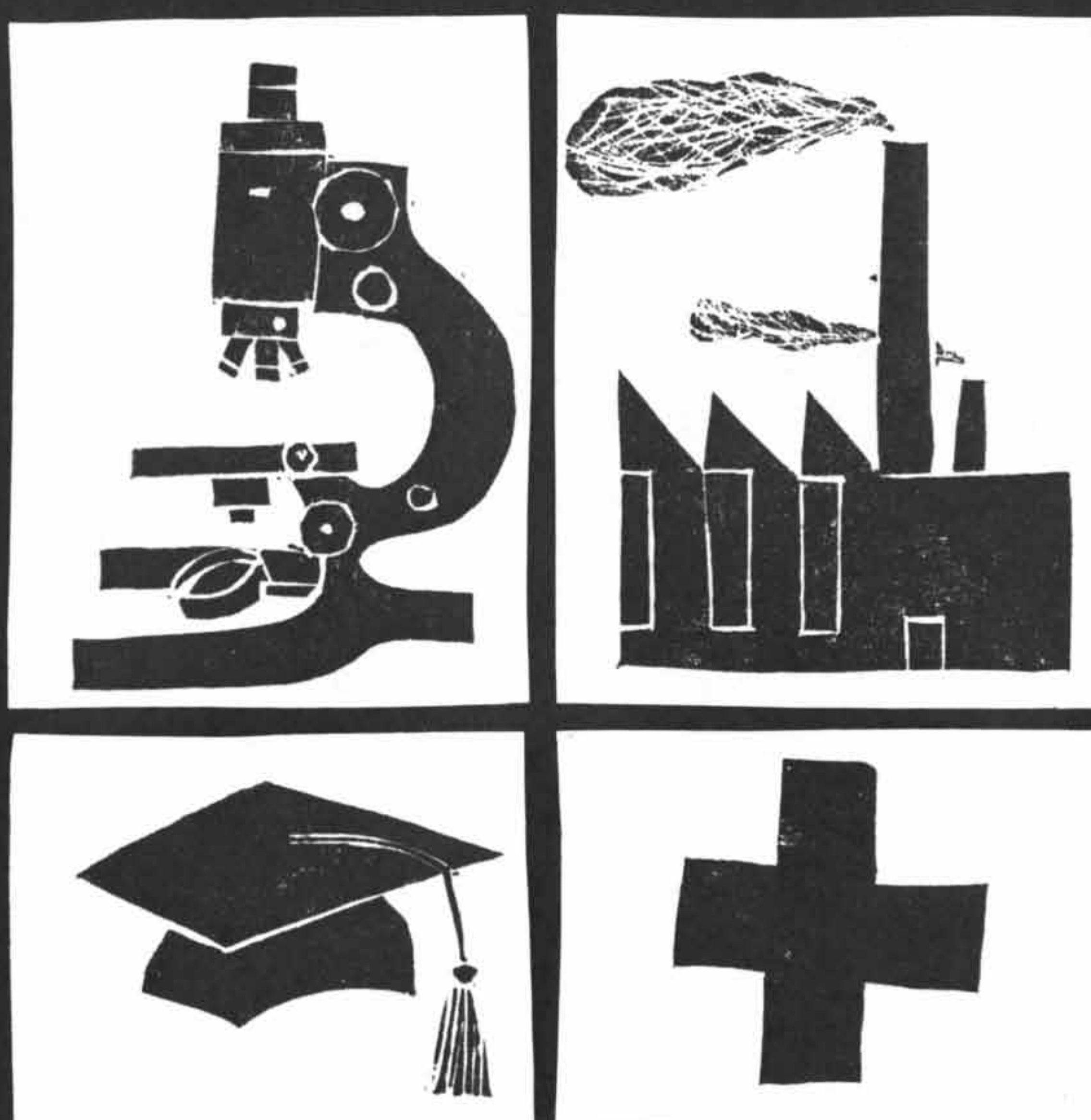
The U. S. Air Force is using 169 NCR 390 computers to compute payrolls and print out paychecks.

Hospitals, like the Central Medico in Puerto Rico, are building their entire administrative programs around an NCR computer.



On-line admission requests received by teletype immediately schedule an examination cubicle and a physician for the patient up to nine months in advance. From this input, the 315 is planning day-to-day requirements, from test tubes to staff to linen, for 65,000 patients. It is also controlling medical records so each patient's history can be instantly located in a single random access file.

Industry is daily finding new needs for computers. A world-famous British food producer is installing a 315 system to analyze sales and to control inventory for an extensive line of products. A major corrugated container manufacturer uses linear programming to scientifically match unrelated orders and schedule material cutting...saving thousands of dollars in trim waste. A leading metal fabricator depends on the 315 for order processing, customer invoicing and production control. Banks and savings and loan associations are using NCR 315 computers to fully automate checking, savings and mortgage loan accounts. Organizations which do not have their own computer are enjoying the speed, accuracy and economy of electronic accounting by going "on-line" to an NCR data center. Data centers in New York, Pittsburgh, Boston, Chicago, San Francisco and Los Angeles are processing accounts for financial institutions as far as 200 miles away. On-line window-posting machines are connected to the computers by telephone lines and accounts are posted instantaneously. NCR computers are handling over 4,800,000 passbook accounts on-line for 127 financial institutions.

NCR computers have virtually revolutionized retailing with "Total Systems" totally automated from initial entry to final reports. From selling floor, credit offices, warehouse receiving and personnel of-

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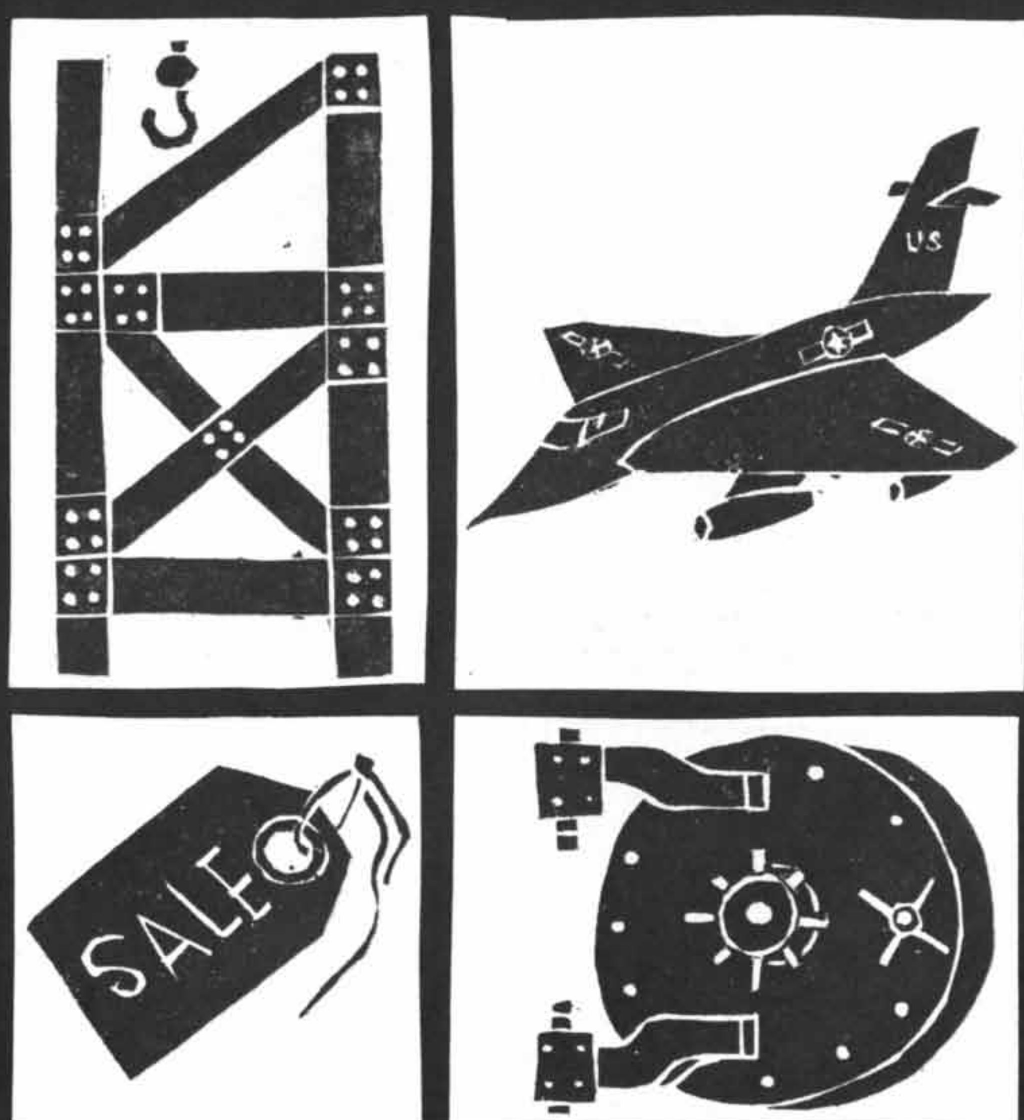
It's what's happening all over. Computers are taking on the tough jobs – the time consuming jobs – to help managements worldwide solve their operating problems. Advanced management science applications are helping solve today's problems and anticipating those of tomorrow.

Linear programming, for example, can consider all variables of all possible investments and determine how funds can best be allocated to provide the greatest return.

Or Multiple Regression Analysis, to take another example, can predict a particular factor – such as the probable risk on a potential borrower in the credit field – on the basis of a measured set of variables – in this instance, sex, age, family background, income, etc.

PERT (Program Evaluation and Review Technique) is being used on every NCR computer from the largest RMC to the smallest 315. It can forecast potential time lags on such projects as building construction. If PERT isolates the electrical phase as a potential holdup, for example, the electrical staff can be increased and the project will proceed on schedule... before the bottleneck occurs.

This is just a minute sample from the NCR "off-the-shelf" package program library. The buyer or user of a 315 or an RMC benefits from one of the most extensive libraries of scientific, business, engineering and advanced management science software – working software – available for any computer system. He's also assured of reliable service: our world-wide team of trained technicians numbers over



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the establishment and operation of the M.I.T. Computation Center.

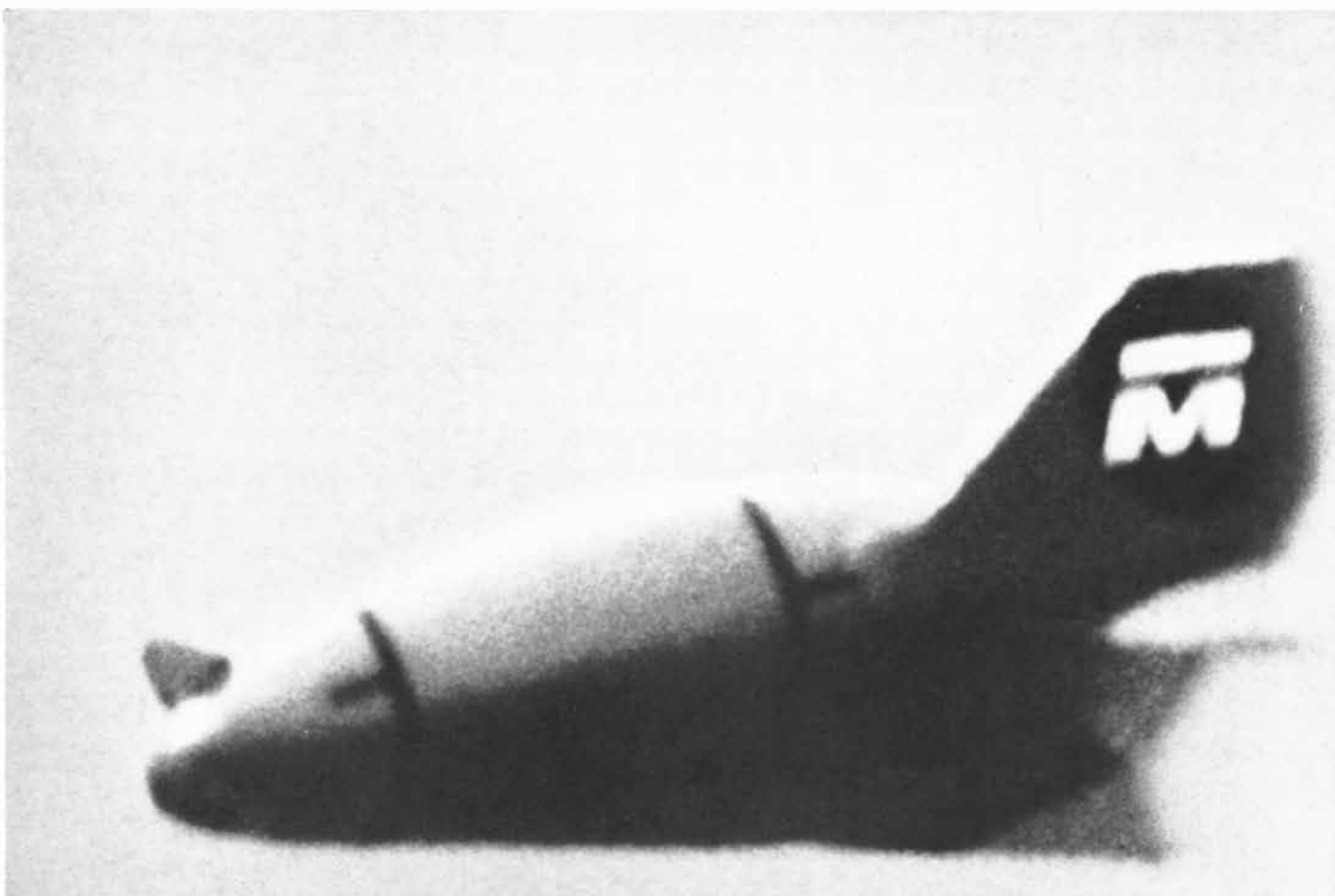
PATRICK SUPPES ("The Uses of Computers in Education") is professor of philosophy and of statistics at Stanford University and also chairman of the department of philosophy and director of the Institute for Mathematical Studies in the Social Sciences at the university. Suppes went to Stanford as an instructor in 1950, the year he obtained a Ph.D. at Columbia University. He did his undergraduate work at the University of Chicago, from which he was graduated in 1943. His extensive writings include two books, *Introduction to Logic* and *Axiomatic Set Theory;* three other books of which he is a coauthor, and several mathematics books for use in elementary schools. His particular interests are mathematical methods in the social sciences and the philosophy of science.

BEN-AMI LIPETZ ("Information Storage and Retrieval") is head of the research department of the Yale University Library. He received a degree in mechanical engineering from Cornell University in 1948 and worked for two years as a technical editor at the Brookhaven National Laboratory. Becoming interested in the problems of managing research, he returned to Cornell for a Ph.D. in administration. Before going to Yale he worked on the development and management of specialized technical-information centers at the Battelle Memorial Institute and did research on machine-aided information systems at the Itek Corporation.

MARVIN L. MINSKY ("Artificial Intelligence") is professor of electrical engineering at the Massachusetts Institute of Technology. He is also director of the artificial-intelligence group there. Minsky was graduated from Harvard College in 1950 and received a doctorate in mathematics at Princeton University in 1954. For the next three years he was a member of the Society of Fellows at Harvard, working on neural theories of learning and on optical microscopy. He joined the mathematics department at M.I.T. in 1958 and transferred to the electrical engineering department in 1962.

MARK DEWOLFE HOWE, who in this issue reviews *The American Jury,* by Harry Kalven, Jr., and Hans Zeisel, with the collaboration of Thomas Callahan and Philip Ennis, is professor of law at the Harvard Law School.

Revolutionary spacecraft will fly back to earth, land at a jet airport.



Here, coming in for a landing, is a test model of the SV-5, an advanced spacecraft being designed by our Martin division for the Air Force. Although it has no wings, the spacecraft will be able to fly back from space, gaining aerodynamic lift from the shape of its fuselage. It will be capable of maneuvering to a landing at a jet airport.

The unusual shape of the SV-5 spacecraft represents one of the great advances in space technology. It is the result of eight years of research and development work by Martin scientists and engineers.

In 1958, the Air Force asked Martin to begin research on a spacecraft that could maneuver both in space and in the atmosphere, then return to earth and land under full control.

Martin's answer is the SV-5 lifting body, a wingless craft which obtains lift from the shape of its body alone.

The SV-5 is designed for launching by a standard launch rocket. Once in space, the craft will be able to maneuver under its own rocket power.

At the end of its mission, the SV-5 will be directed back into the atmosphere. From a blazing reentry speed of 17,500 mph, it will gradually slow to aircraft speeds, at all times under control. The craft will then be guided to a designated landing runway. After maintenance, it will be ready for another launch.

A lifting body spacecraft could undertake many types of missions, manned or unmanned. It could shuttle crews and supplies between the earth and manned satellites. Or go up to inspect other spacecraft. Or fly rescue and repair missions.

Four unmanned SV-5 models will be launched in sub-orbital flights over the Pacific, the first late this year.

Next year, manned rocket-powered models will be dropped from an Air Force B-52 to test stability and landing characteristics. Further data will be gained from a jet-powered model of the spacecraft, which will be flown by Martin test pilots.

Research data from these manned and unmanned vehicles will furnish the knowledge needed for manned space tests.

The several divisions of Martin Marietta produce a broadly diversified range of products, including missile systems, space launchers, nuclear power systems, spacecraft, electronic systems, chemicals and construction materials. Martin Marietta Corporation, 277 Park Avenue, New York, N.Y.

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Both use the same basic design concept. Both have the same size memories. Both are expandable. Both use the same instructions, use the same software libraries.

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The PDP-8/S adds in 32 microseconds (compared with 3.0 microseconds for its parent). If you need the speed, the PDP-8 is for you.

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Software includes real-time FORTRAN IV, a versatile macro assembler, a 6 and 9 digit floating point arithmetic package, an on-line editor, an on-line debugging system, a control monitor, and a modular I/O programming system. Basic software is fully compatible with the PDP-7. Extended software package expands to fully utilize all configurations.

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Variable Sweep Wings: A report from General Dynamics

A major step forward in aircraft design:

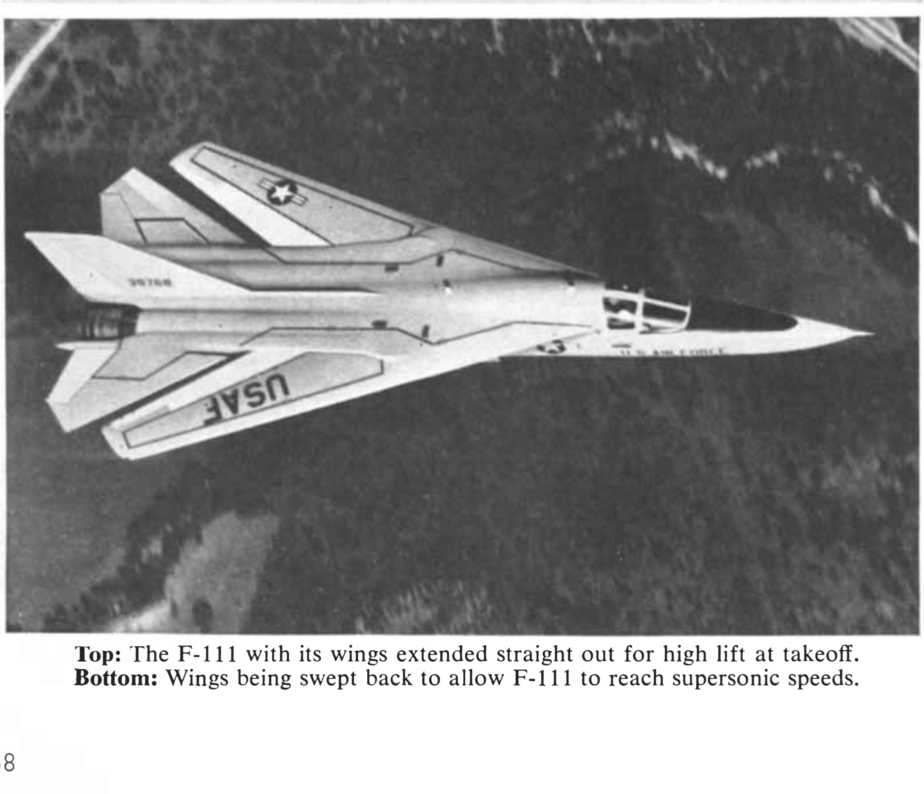
This week, several pilots redesigned their airplanes in flight. Shortly after takeoff, each pilot moved a trombone-shaped slide in his cockpit and folded back the wings of his plane.

The ability to do this made the F-111's they were flying the first aircraft that can (1) operate from short landing fields, *and* (2) fly economically for long subsonic cruise ranges or ferry itself across an ocean, *and* (3) strike supersonically at treetop height *or* dash at two-and-a-half times the speed of sound at an altitude of 12 miles.

The key is its variable sweep wing. Today the first 17 developmental F-111's, built by General Dynamics, are daily demonstrating the feasibility of a movable wing—a development that finally makes a truly multipurpose airplane practical.

The matter of flight envelope:

Every aircraft has a specific "envelope"—a set of limitations, or boundaries, of speed and altitude, within which it can operate effectively. The final design of a plane depends upon which of several possible purposes is most important.



Top: The F-111 with its wings extended straight out for high lift at takeoff.
Bottom: Wings being swept back to allow F-111 to reach supersonic speeds.

A long wing extended straight out is best for short takeoff and landing, long range and endurance, or high load-carrying characteristics. For the high lift demanded, a large amount of wing surface is needed.

But as speed increases, less lift is needed from the wings. In fact, at high speeds, large wings increase resistance from the air. Such an airplane can be pushed to supersonic speed by brute power, but not efficiently.

This resistance is commonly called drag, and one way to reduce it has been to sweep the wing back. For instance, the modern passenger jet, whose wings are partially swept back, can fly efficiently for long distances just below the speed of sound. But the swept wing provides less lift, and such aircraft need long runways, sometimes up to two miles long, and special braking devices.

Very high speeds—faster than sound—can best be reached with a very small wing, sometimes in a triangle or delta shape. But the still lower lift can require even longer runways, and additional braking devices such as drogue parachutes. The very small wing offers considerably less fuel efficiency for long-range, subsonic flight.

Three aircraft in one:

A wing whose position can be changed by a pilot *in flight* gives a single airplane the special talents of all three types. With the wing fully extended, the aircraft has high lift for short takeoff or landing or high-load capacity. With the wings partially swept, efficient long-range subsonic flight becomes practical. Pulling the wings all the way back to their smallest exposed area provides supersonic dash, without having sacrificed either high lift or cruise economy.

Previous—and impractical—attempts to achieve variable wing geometry go all the way back to 1911. The chief problem: an undesirable relationship between center of gravity and center of lift as the wings moved would cause an airplane to nose up and down sharply—become longitudinally unstable.

How it operates:

Not until 1960 did the National Aeronautics and Space Administration conceive the answer to this instability—simultaneously sweeping both wings around separate pivot points which were moved out on the wing root rather than having a single pivot in the center of the fuselage. The concept has been refined and developed by General Dynamics through more than 22,000 hours of wind tunnel testing, and more than 25 million man-hours of design and development.

The F-111's variable wing can be moved in flight from its fully extended position (technically with 16° of sweep measured at the leading edge) to a full sweep of 72.5°, with the wings tucked back against (and much of them actually inside) the fuselage for a narrow delta shape. The position of the wings can be set and held at any position between these two extremes, with the pilot himself deciding what wing setting is best for maximum performance in a given set of circumstances. He can normally lever the wings from one extreme to the other in about twenty seconds.

The precision of design is so exact and the wing so balanced that negligible elevator trim is needed to compensate for full sweep of the wing.

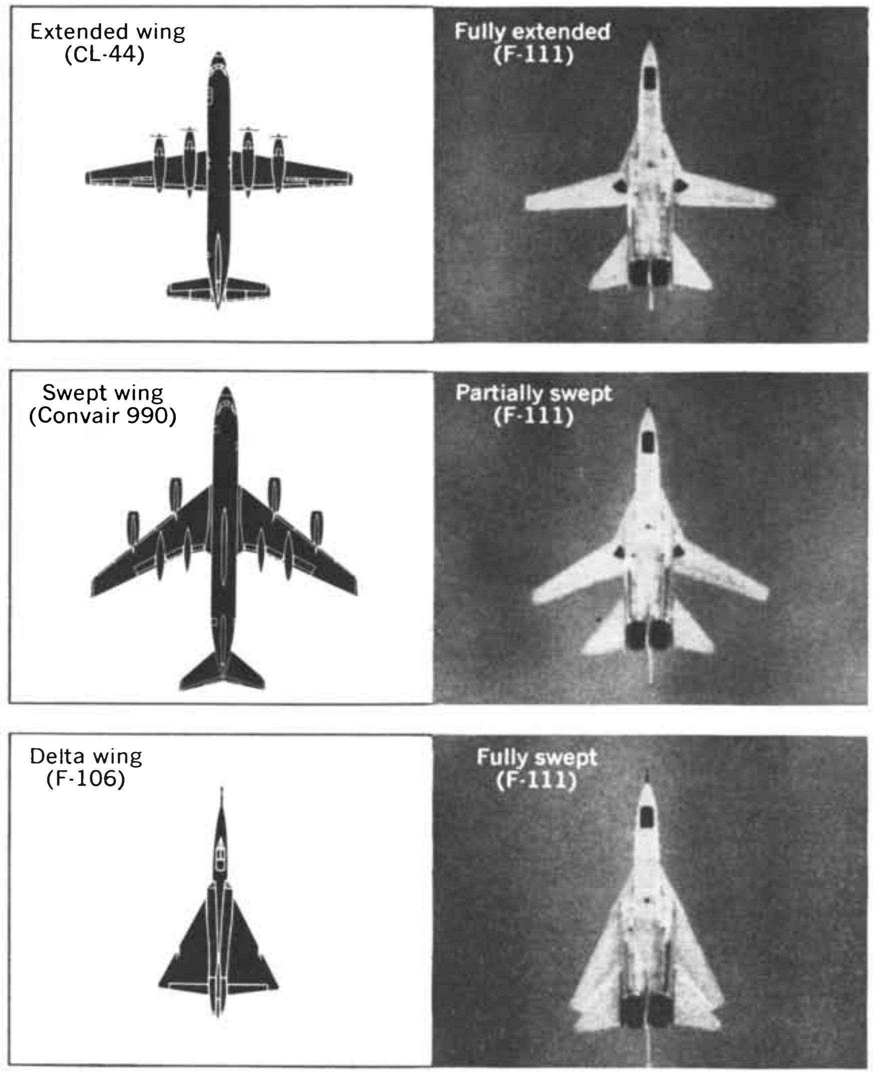
Heart of the system:

The heart of the F-111's variable sweep system is a 14-foot steel yoke across the fuselage (see drawing below).

The movable portions of each wing are fastened to the yoke by 8½-inch diameter high-strength steel pivot pins. Forward of the yoke hydraulically powered actuators, responding to the pilot's control selection, move the wings from one position to another.

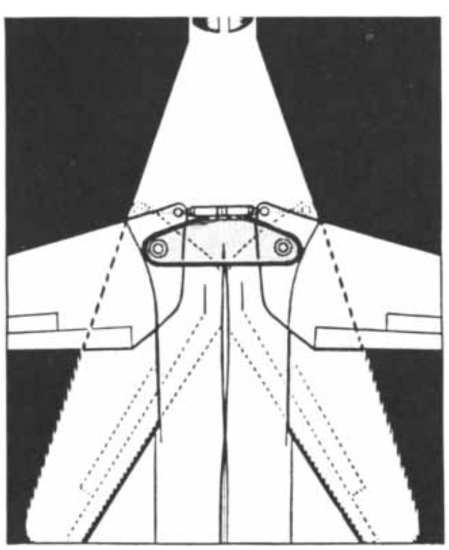
For additional high lift at takeoff and landing, full span slats and flaps are incorporated into the wing. The wing itself is ingeniously tapered so that much of its area when fully extended is highly cambered—that is, with a relatively thick curve for greater lift—and thin at the area remaining exposed when wings are swept back for high-speed flight.

How wing configuration determines flight envelope



Left, top to bottom: Drawings of planes flying today. Extended wing of transport provides relatively short takeoff and landing with heavy loads. Swept wing of passenger liner provides less lift, but allows the plane to fly efficiently just below the speed of sound. Small delta wing of military fighter reduces air resistance (drag) and allows the plane to fly at supersonic speeds.

Right, top to bottom: Photos of the F-111 show how the variable sweep wing gives it the advantages of the extended wing, swept wing and delta wing—all in one plane.

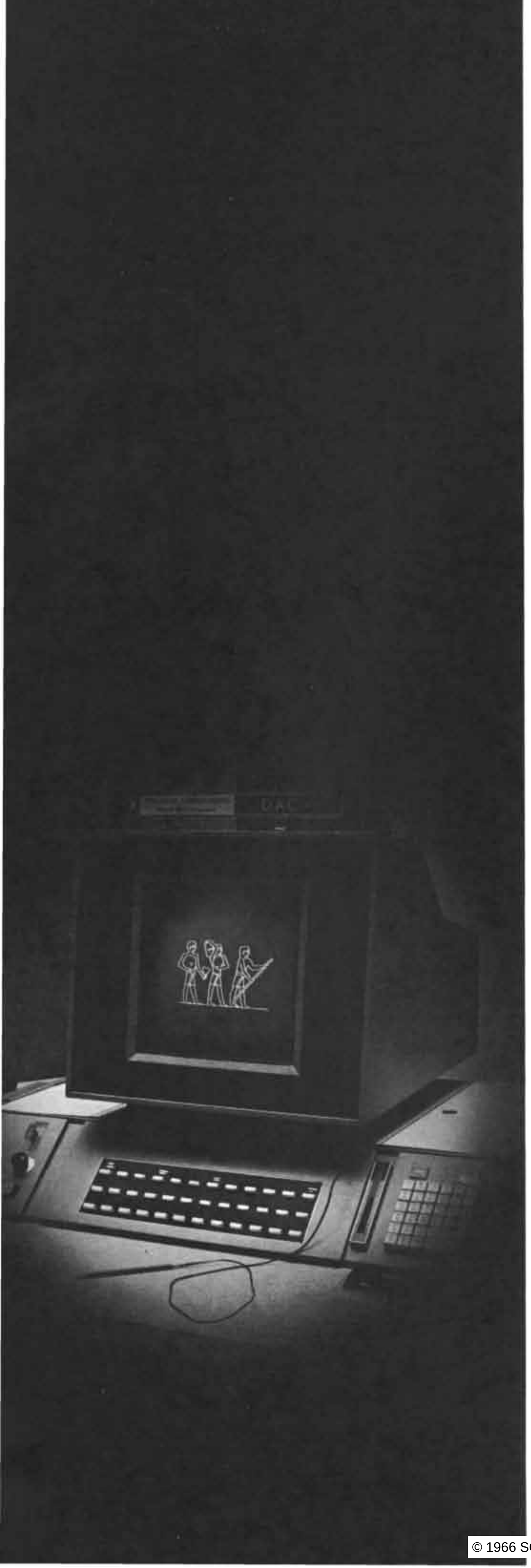


How the wing works. A 14-foot steel yoke, with its 8½-inch diameter pins, on which the wings pivot, is the heart of the variable sweep winged F-111. The yoke and pins support the whole plane in flight. A jackscrew just forward of the yoke actuates the wings during sweep.

The future for the sweep wing:

Since the Wright Brothers' first breakthrough in the art of manned flight, there have been relatively few major advances in the basic art of airplane building. One was the introduction of light aluminum structures, another the introduction of the turbine—better known as the jet—engine for propulsion.

The variable sweep wing represents a similar major step forward. For any category of aircraft—military, commercial or private—where the combination of very high-speed flight, long economic cruise and high lift for easy takeoff and landing is desired, the variable sweep wing sets the new standard. Even space ships may ultimately incorporate some form of variable geometric wing to make them more maneuverable within different atmospheres.



One of a series briefly describing GM's research in depth

Pictures spoken here

If ancient man had invented the digital computer, we'd have no problem. His language was pictures.

But the alphabet came along, and we're saddled with computers whose native tongue is one of letters, numbers, and punched cards. Some modern men speak this language, too. But not all.

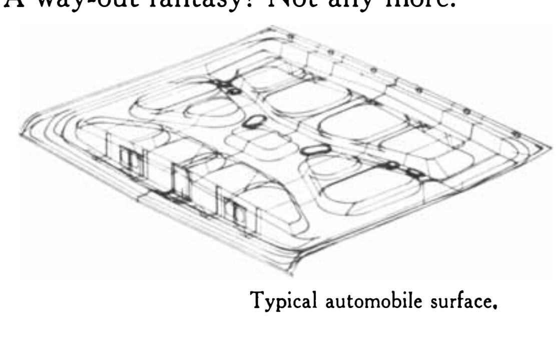
The designer, for instance, represents ideas in drawings. With proper schooling, so can the computer. Two years ago we announced the first such development: the DAC system, design augmented by computers. It used an educated computer speaking some of the designer's language. That was the first big step . . . a move to free the man from routine tasks, to let him spend more time creatively.

What's followed has been step-by-step improvement, bringing us closer to man-machine communication directly in graphics.

Without writing program statements, the designer now can use the computer to generate, manipulate, and evaluate free-form lines and surfaces. Every item in a designer's picture is a variable under his control. As he reviews and selects items on our laboratory console screen he can, for example, gradually develop a complex three-dimensional surface for an automobile.

The goal: Let the designer put a rough sketch on the computer console and make instantaneous changes as he develops his idea into a final exact design—all without translating into computer language.

A way-out fantasy? Not any more.



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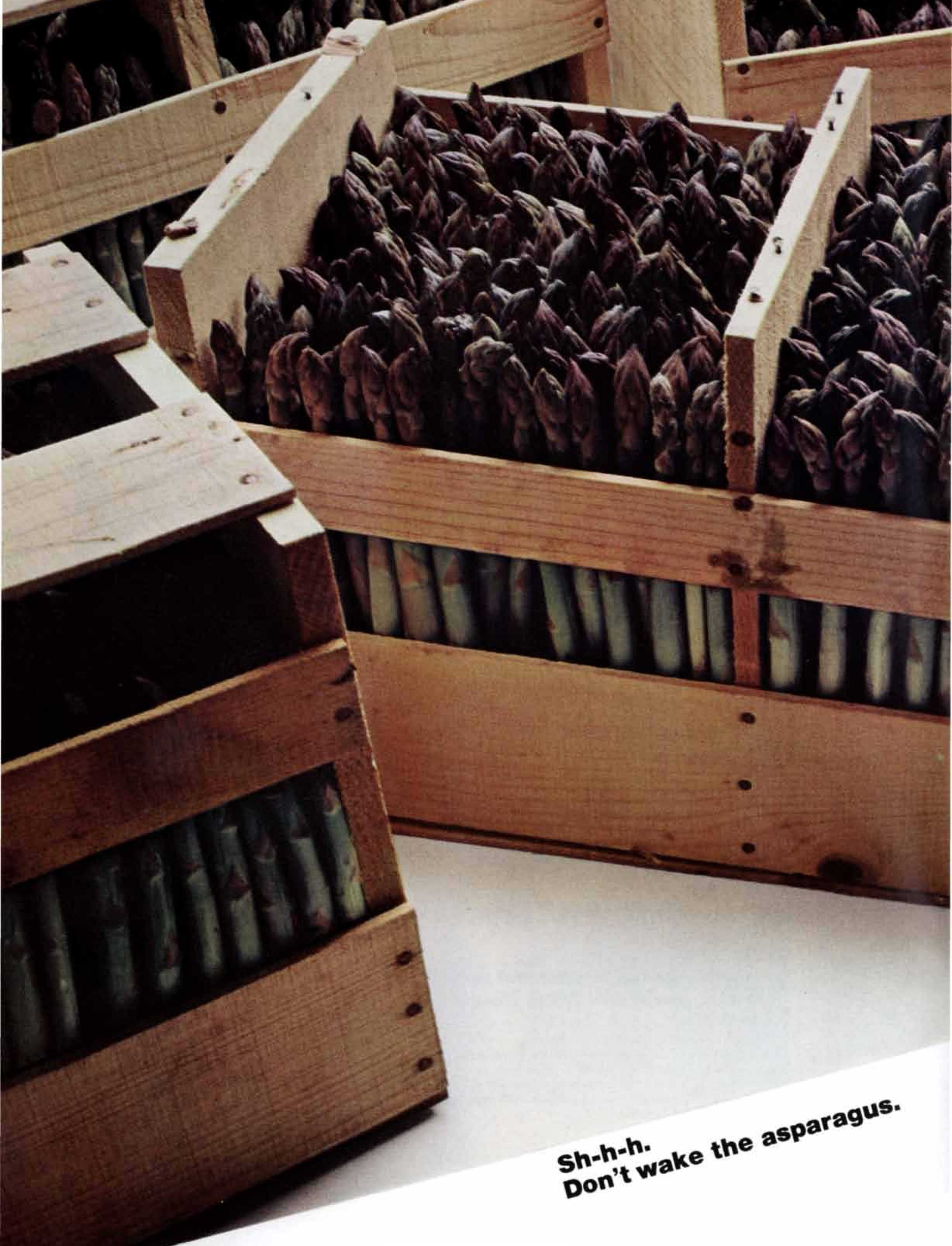
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Don't wake the asparagus.

If you want to keep asparagus fresh, make sure that it gets plenty of beauty sleep on its way to market. Just ship it under Polarstream liquid nitrogen refrigeration.

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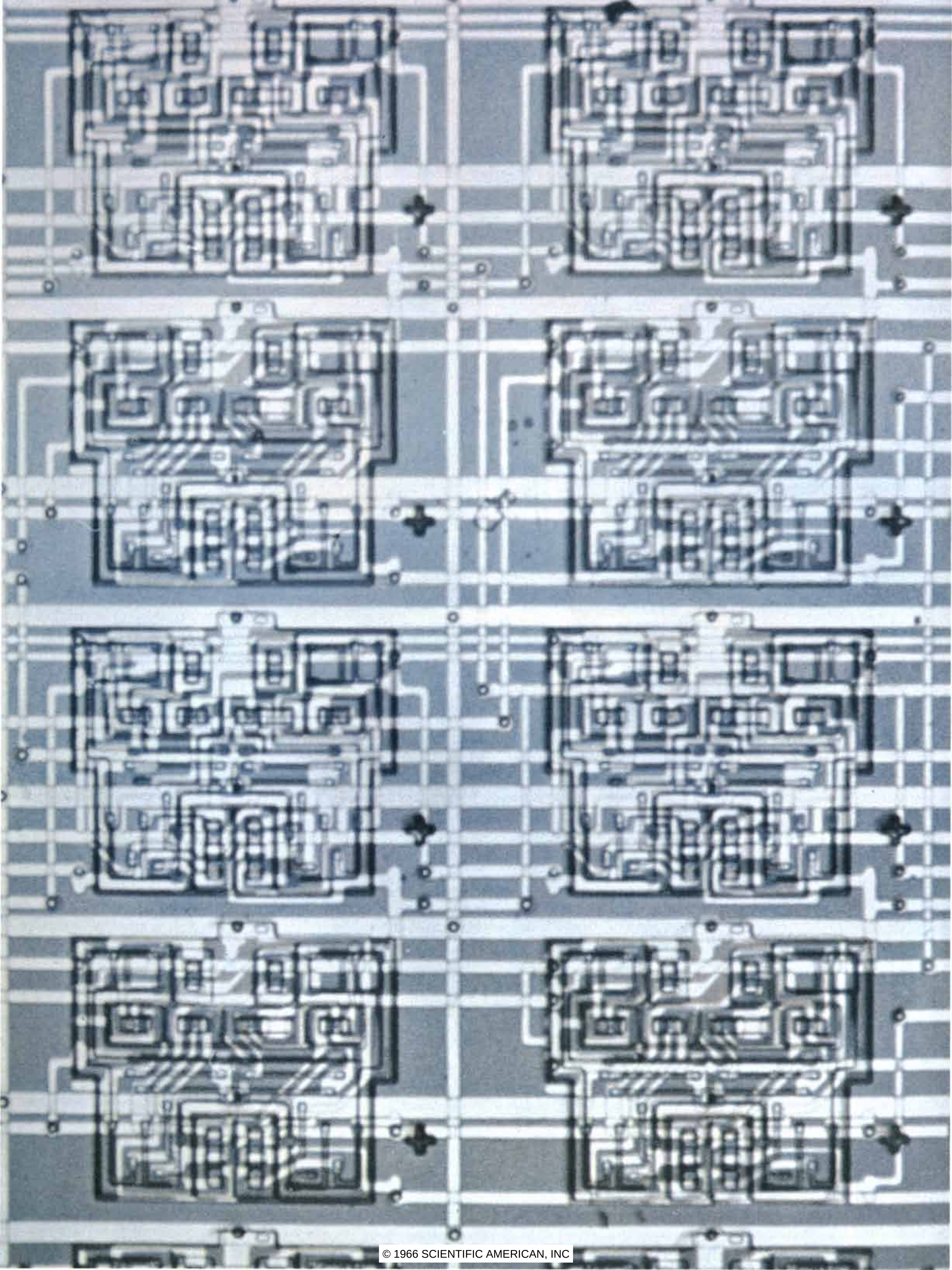


Established 1845 SCIENTIFIC AMERICAN September 1966 Volume 215 Number 3

Information

Presenting an issue about its processing by computers. The moral of this introductory article: computers, far from robbing man of his individuality, enable technology to adapt to human diversity

by John McCarthy

The computer gives signs of becoming the contemporary counterpart of the steam engine that brought on the industrial revolution. The computer is an information machine. Information is a commodity no less intangible than energy; if anything, it is more pervasive in human affairs. The command of information made possible by the computer should also make it possible to reverse the trends toward mass-produced uniformity started by the industrial revolution. Taking advantage of this opportunity may present the most urgent engineering, social and political questions of the next generation.

A computer, as hardware, consists of input and output devices, arithmetic and control circuits and a memory. Equally essential to the complete portrait is the program of instructions—the "software"—that puts the system to work. The computer accepts information from its environment through its input devices; it combines this information, according to the rules of the program stored in its memory, with information that is also stored in its memory, and it sends information back to its environment through its output devices.

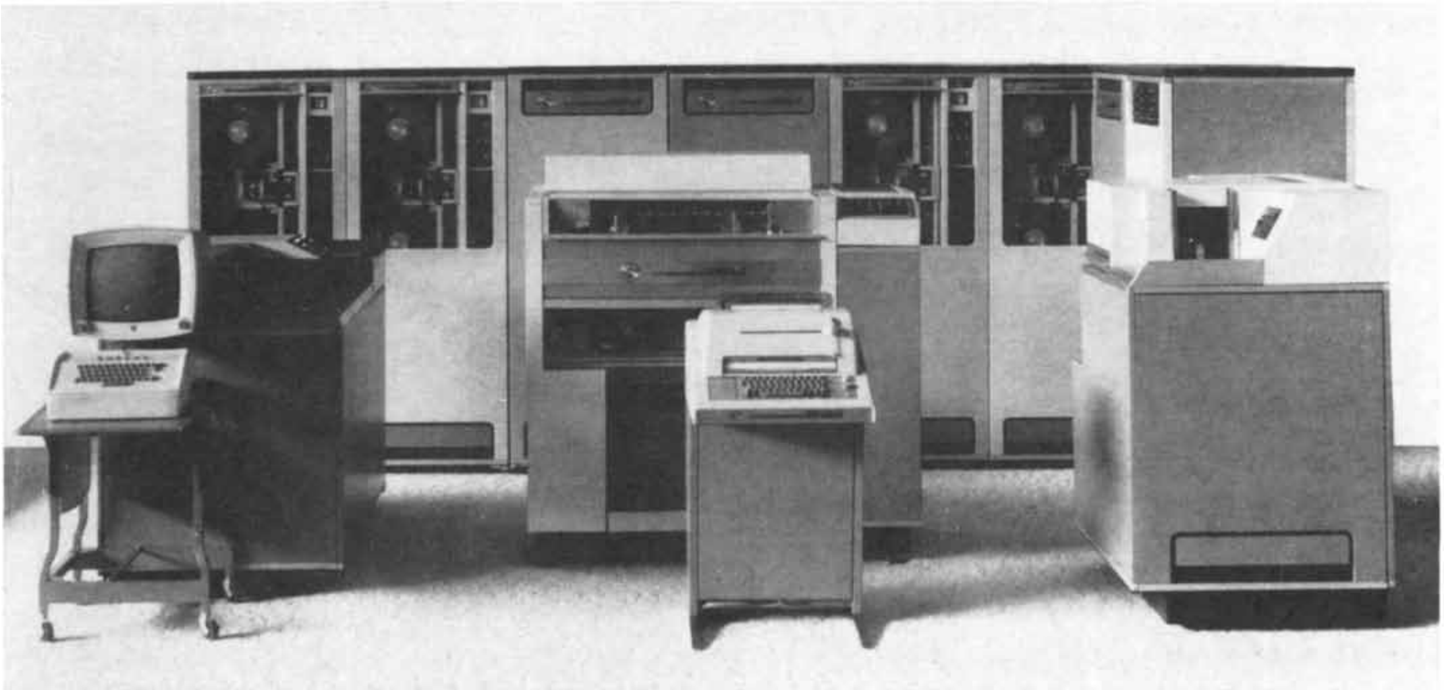
The human brain also accepts inputs of information, combines it with information stored somehow within and returns outputs of information to its environment. Social institutions—such as the legislature, the law, science, education, business organizations and the communication system—receive, process and put out information in much the same way. Accordingly, in common with the computer, the human brain and social institutions may be regarded as information-processing systems, at least with respect to some crucial functions. The study of these entities as such has led to new understanding of their structures.

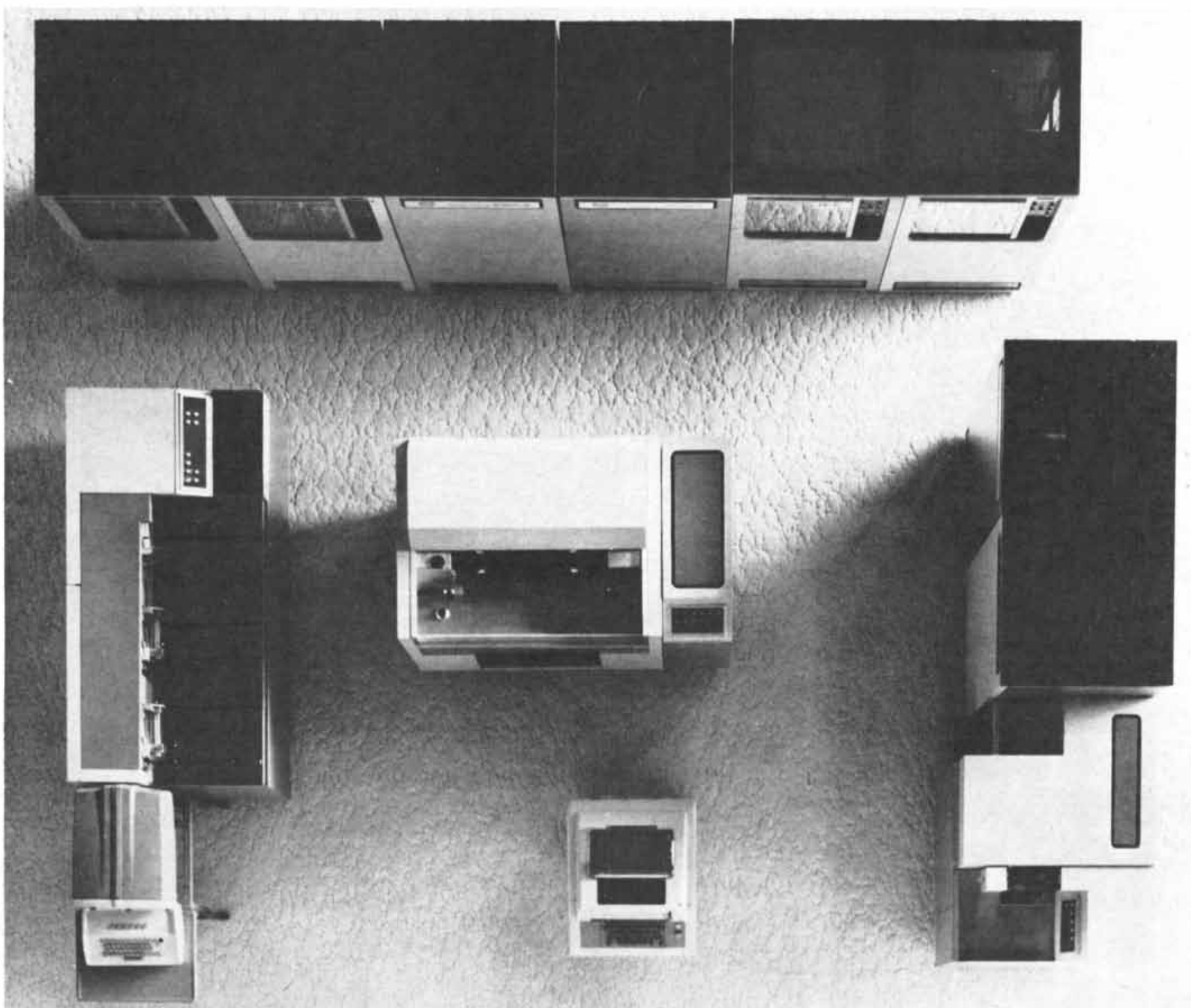
The installation of computers in certain organizations has already greatly increased the efficiency of some of the organizations. In the 15 or 20 years that computers have been in use, however, it has become clear that they do not merely bring an increase in efficiency. They induce basic transformation of the institutions and enterprises in which they are installed.

In the first place, computers are a million to a billion times faster than humans in performing computing operations. This follows from the fact that their working parts now change state in a few millionths or billionths of a second. Why should this quantitative change in speed produce a qualitative change in human activities that are facilitated by a computer? It might seem that there is no way to use such speeds outside of the missile business and other exotic undertakings. The answer is that the increase in speed has meant the building of computers with the capacity to handle information on a correspondingly larger scale. The interaction of high-speed, high-capacity computers with their environment is often continuous, with many input and output devices operating simultaneously with the ongoing internal computation.

The computer is, furthermore, a universal information-processing machine. Any calculation that can be done by any machine can be done by a computer, provided that the computer has a program describing the calculation. This was proved as a general proposition by the British mathematician A. M. Turing as early as 1936. It applies to the most rudimentary theoretical system as well as to the big general-purpose machines of today that make it possible, in practice, to write new programs instead of having to build new machines.

MICROELECTRONIC CIRCUITS of the kind shown on the opposite page can be regarded as the nerve tissue of the next generation of computers. The circuits, which are enlarged about 200 diameters, are part of a "complex bipolar array chip" made by Fairchild Semiconductor. Each of the eight complete circuits shown (*dark gray*) is a functional unit consisting of 18 transistors and 18 resistors. These units are connected by a larger microelectronic network (*white*); there are 28 units in the entire chip. Some recent computers incorporate microelectronic circuits, but the circuits are not connected microelectronically. Possibly microelectronic circuits will be used not only as logic elements but also as memory elements.





TYPICAL COMPUTER INSTALLATION includes components of the kind shown here in front and top views; the components are identified in the diagram at right. The heart of the system, which is a computer in the Spectra 70 series of the Radio Corporation of America, is the central processor and memory unit; the other units serve for input, output and storage of data. The input devices are

The speed, capacity and universality of computers make them machines that can be used to foster diversity and individuality in our industrial civilization, as opposed to the uniformity and conformity that have hitherto been the order of the day. Decisions that now have to be made in the mass can in the future be made separately, case by case. To take a practical example, it can be decided whether or not it is safe for an automobile to go through an intersection each time the matter comes up, instead of subjecting the flow of automobiles to regulation by traffic lights. A piece of furniture, a household appliance or an automobile can be designed to the specifications of each user. The decision whether to go on to the next topic or review the last one can be made in accordance with the interests of the child rather than for the class as a whole. In other words, computers can make it possible for people to be treated as individuals in many situations where they are now lumped in the aggregate.

The quality of such individual response and attention is another matter. It will depend on the quality of the programs. The special attention of a stupid program may not be worth much. But then the individual can write his own program.

The future that is contemplated here has come into view quite abruptly during the past few years. According to a report published by the American Federation of Information Processing Societies (AFIPS), there were only 10 or 15 computers at work in the U.S. in 1950. Today there are 35,200, and by 1975 there will be 85,000. Investment in computers will rise from $8 billion to more than $30 billion by 1975. Present installations include 2,100 large systems costing about $1 million each; in 1975 there will be 4,000 of these. Even the medium and small systems that are in use today have a capacity equal to or exceeding that of the 1950 generation.

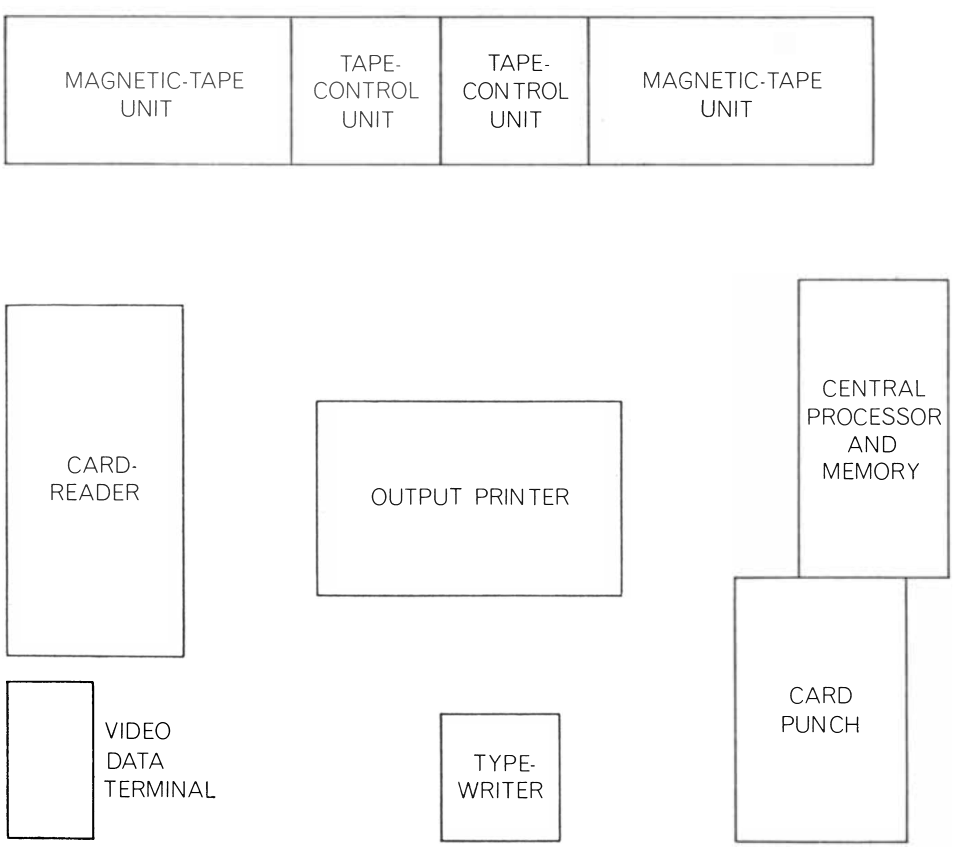
A scientific problem that took an hour on a big 1950 machine at 1,000 operations per second can be run on the fastest contemporary computers in less than half a second. Allowing another 3.5 seconds to transfer the yield to an external storage memory for later printing, it can be said that program running time has been reduced from an hour to three or four seconds. This reflects the impressive recent progress in the design and manufacture of computer hardware.

Big computers are currently equipped with internal memories—the memory actively engaged in the computation under way—that usually contain 10 or 12 million minute ring-shaped ferrite "cores" in three-dimensional crystalline arrays. Each core is capable of storing one "bit," or unit, of information. Along with the replacement of the vacuum tube by the transistor and now the replacement of the transistor by the microelectronic circuit [*see illustration on page 64*] there has come a steep increase in the speed of arithmetic and control circuits over the past 10 years. The miniaturization of these circuits (from hundreds of circuits per cubic foot with vacuum-tube technology to hundreds of thousands and prospectively millions of circuits per cubic foot with solid-state technology) has speeded up operations by reducing the distance an impulse has to travel from point to point inside the computer.

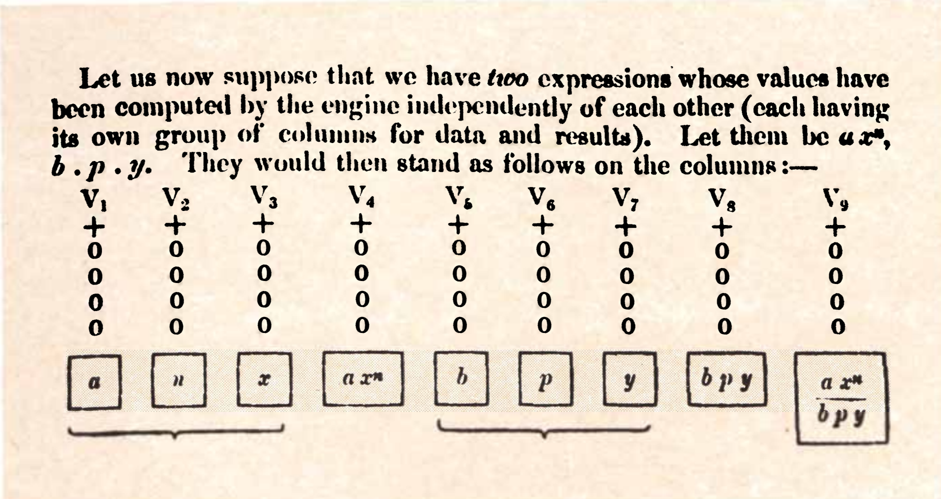
As increases in speed and capacity have realized the inherent universality of the computer, expenditures for programming have been absorbing an increasing percentage of total installation costs. The U.S. Government, with a dozen or so big systems serving its military and space establishments, is spending more than half of its 1966 outlay of $844 million on software. Without doubt the professions in this field—those of system analyst and programmer—are the fastest-growing occupations in the U.S. labor force. From about 200,000 in 1966 it is estimated that their numbers will increase to 500,000 or 750,000 by 1970. Courses in programming are now offered in many universities and even in some high schools. In a liberal education an exposure to programming is held to be as bracing as an elementary course in mathematics or logic.

Calculating devices have a history that goes back to the ancient Greeks. The first mechanical digital calculators were made by Blaise Pascal in the 17th century. In the mid-19th century Charles Babbage proposed and partially constructed an automatic machine that would carry out long sequences of calculations without human intervention. Babbage did not succeed in making his machine actually work—although he might have, had he used binary instead of decimal notation and enjoyed better financial and technical support.

In the late 1930's Howard H. Aiken of Harvard University and George R. Stibitz of the Bell Telephone Laboratories developed automatic calculators using relays; during World War II, J. Presper Eckert and John W. Mauchly of the University of Pennsylvania developed ENIAC, an electronic calculator. As early as 1943 a British group had an

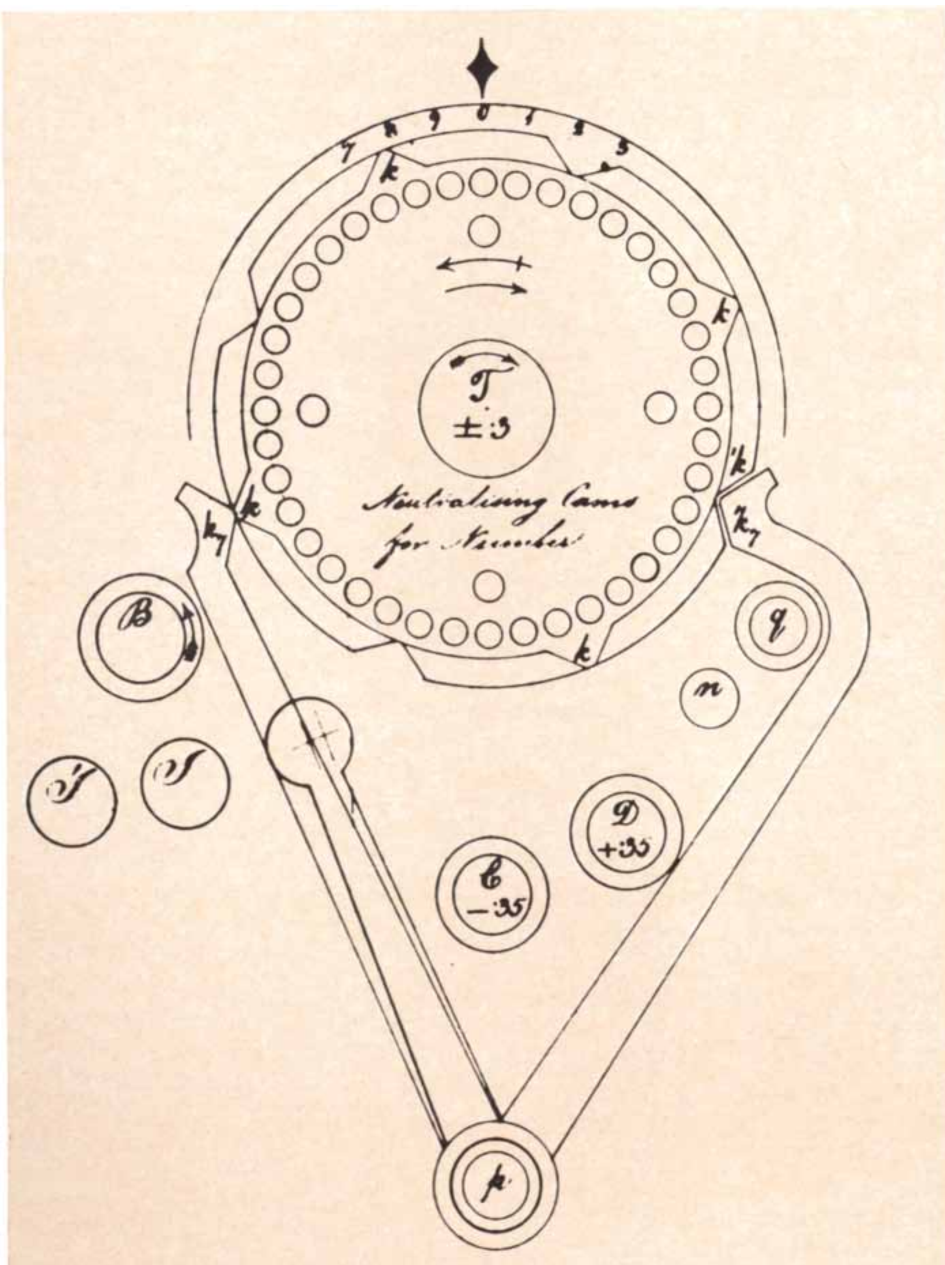


the typewriter, with which the operator communicates with the machine, and the card-reader, for which the card-punch is an adjunct. The main output devices are the printer and the video data terminal, which employs a cathode ray tube. The tape units store data.


Let us now suppose that we have *two* expressions whose values have been computed by the engine independently of each other (each having its own group of columns for data and results). Let them be $a x^n$, $b . p . y$. They would then stand as follows on the columns:—

V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9
+	+	+	+	+	+	+	+	+
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
a	n	x	$a x^n$	b	p	y	$b p y$	$\frac{a x^n}{b p y}$

EARLY PROGRAM was written for Charles Babbage's "analytical engine" by Lady Lovelace, who was the daughter of Lord Byron. She wrote the program, which was for computing the number series known as Bernoulli numbers, to show what the engine could do. The program, of which this is a fragment, was published in 1840 in *Taylor's Scientific Memoirs.*



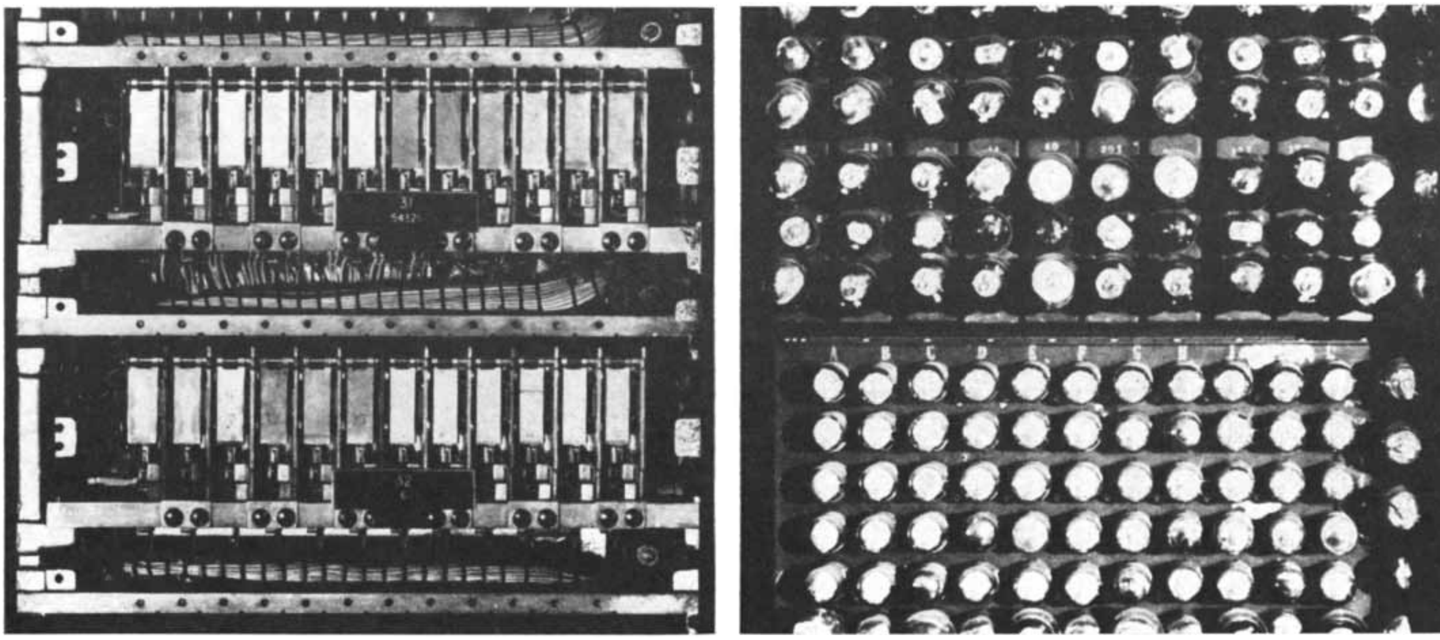
PART OF ANALYTICAL ENGINE was drawn by Babbage. This drawing, one of many that he made for the engine, bears the inscription "Neutralising Cams for Number." Financial and technological difficulties prevented Babbage from completing the machine.

electronic computer working on a wartime assignment.

Strictly speaking, however, the term "computer" now designates a universal machine capable of carrying out any arbitrary calculation, as propounded by Turing in 1936. The possibility of such a machine was apparently guessed by Babbage; his collaborator Lady Lovelace, daughter of the poet Lord Byron, may have been the first to propose a changeable program to be stored in the machine. Curiously, it does not seem that the work of either Turing or Babbage played any direct role in the labors of the men who made the computer a reality. The first practical proposal for universal computers that stored their programs in their memory came from Eckert and Mauchly during the war. Their proposal was developed by John von Neumann and his collaborators in a series of influential reports in 1945 and 1946. The first working stored-program computers were demonstrated in 1949 almost simultaneously in several laboratories in Britain and the U.S. The first commercial computer was the Eckert-Mauchly UNIVAC, put on the market in 1950.

Since that time progress in the electronic technology of computer circuits, the art of programming and programming languages and the development of computer operating systems has been rapid. No small part in this development has been played by the U.S. Government, which is always in the market for the latest and biggest systems available. It is not too much to say that the systems designed for the industry's biggest customer have been the prototypes for each major advance in computer hardware. The creation of the high-speed computer has been as central to the contemporary revolution in the technology of war as the intercontinental missile and the thermonuclear warhead.

The basic unit of information with which these machines work is the bit. Any device that can be in either of two states, such as a ferrite core or a transistor, can store a single bit. Two such devices can store two bits, three can store three bits, and so on. Consider a five-bit register made of five one-bit devices. Since each device has two states, represented, say, by 0 and 1, the five together have 2^5, or 32, states. The combinations from 00000 to 11111 can be taken to represent the binary numbers from 0 to 31. They can also be used to encode the 26 letters of the alphabet, with six combinations left over to represent word spaces and punctuation. This would permit representation



FIRST MODERN COMPUTERS were the Mark I and the ENIAC (Electronic Numerical Integrator and Calculator). The former had electromechanical relays (*left*) as its key parts, the latter vacuum tubes (*right*). A comparison of these parts with the microelectronic circuits illustrated on page 64 will indicate how far miniaturization has progressed. Both the Mark I and the ENIAC have been disassembled. The portion of the Mark I shown here is now at Harvard University; panel from ENIAC is at U.S. Military Academy.

of words and sentences by strings of five-bit groups. (Actually, to accommodate uppercase and lowercase letters, the full assortment of punctuation marks, the decimal digits and so on it is now customary to use seven bits.)

For many purposes, however, it is better not to be specific about how the information is coded into bits. More important is the task of describing the kinds of information to be dealt with, the basic operations to be carried out on them and the basic tests to be performed on the information in order to decide what to do next. For bits the basic operations are the logical operations $\cdot$, $+$ and $-$ (the last usually placed above a symbol, as in $\bar{A}$), which are read "and," "or" and "not" respectively. Operations are defined by giving all the cases. Thus $\cdot$ is defined by the equations $0 \cdot 0 = 0$, $1 \cdot 0 = 0$, $0 \cdot 1 = 0$, and $1 \cdot 1 = 1$. The basic decision concerning a bit is whether it is 0 or 1. Designers of computers do much of their work at the level of bits [*see illustration on next page*]. They have systematic procedures, as the following article by David C. Evans shows, for translating logical equations into transistor circuits that carry out the functions of these equations.

At the next level above bits come numbers. On numbers the basic operations are addition, subtraction, multiplication and division [*see illustration on page 71*]. The basic tests are whether two numbers are equal and whether a number is greater than zero. Programmers are generally able to work with numbers because computer designers build the basic operations on numbers out of the logical operations on bits in the design of the circuits in the machine.

Another kind of information is a string of characters, such as A or ABA or ONION. It is well to include also the null string with no characters. A basic operation on characters may be taken to be concatenation, denoted by the symbol *. Thus ABC*ACA = ABCACA. The other basic operations are "first" and "rest." Thus first(ABC) = A and rest(ABC) = BC. The basic tests on strings are whether the string is null and whether two individual characters are equal.

Out of one kind of information, then, more elaborate kinds of information can be built; numbers and characters are built out of bits, and strings are built out of characters. Similarly, the operations and tests for the higher forms of information are built up out of the operations and tests for the lower forms. One can represent a chessboard, for example, as a table of numbers giving for each square the kind of piece, if any, that occupies it. For chess positions a basic operation gives the list of legal moves from that position. A picture may be similarly represented by an array of numbers expressing the gray-scale value of each point in the picture. The *Mariner IV* pictures of Mars were so represented during transmission to the earth, and this representation was used in the memory of the computer by the program that removed noise and enhanced contrast. Christopher Strachey shows in this issue how programmers put together the basic operations and tests for a given class of information in designing a program to treat such information [see "System Analysis and Programming," by Christopher Strachey, page 112].

What computers can do depends on the state of the art and science of the programming as well as on speed and memory capacity. At present it is straightforward to keep track of the seats available on each plane of an airline, to compute the trajectory of a space vehicle under the gravitational attraction of the sun and planets or to generate a circuit diagram from the specifications of circuit elements. It is difficult to predict the weather or to play a fair game of chess. It is currently not clear how to make a computer play an expert game of chess or discover significant mathematical theorems, although investigators have ideas about how these things might be done [see "Artificial Intelligence," by Marvin L. Minsky, page 246].

Input and output devices also play a significant part in making the capacity of a computer effective. For the engineering computations and the bookkeeping tasks first assigned to computers it seemed sufficient to provide them with punched-card-readers for input and line-printers for output, together with magnetic tapes for storing large quantities of data. To fly an airplane or a missile or to control a steel mill or a chemical plant, however, a computer must receive inputs from such sensory organs

LOGIC

	YES	NO
	1	0

NUMERATION

0	0	0	0
1	1	1	1
2	10	2	10
4	100	3	2 1 11
8	1000	4	100
16	10000	5	4 1 101
32	100000	6	4 2 110
64	1000000	7	4 2 1 111
128	10000000	8	1000
256	100000000	9	8 1 1001

SEVEN-BIT CODE

COLUMNS

BITS				b_7 b_6 b_5	0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b_4	b_2	b_3	b_1		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	0	0	0	**0**	NUL	DLE	SP	0	`	P	@	p
0	0	0	1	**1**	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	**2**	STX	DC2	"	2	B	R	b	r
0	0	1	1	**3**	ETX	DC3	#	3	C	S	c	s
0	1	0	0	**4**	EOT	DC4	$	4	D	T	d	t
0	1	0	1	**5**	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	**6**	ACK	SYN	&	6	F	V	f	v
0	1	1	1	**7**	BEL	ETB	'	7	G	W	g	w
1	0	0	0	**8**	BS	CAN	(	8	H	X	h	x
1	0	0	1	**9**	HT	EM	)	9	I	Y	i	y
1	0	1	0	**10**	LF	SS	*	:	J	Z	j	z
1	0	1	1	**11**	VT	ESC	+	;	K	[	k	{
1	1	0	0	**12**	FF	FS	,	<	L	~	l	¬
1	1	0	1	**13**	CR	GS	–	=	M	]	m	}
1	1	1	0	**14**	SO	RS	.	>	N	∧	n	|
1	1	1	1	**15**	SI	US	/	?	O	—	o	DEL

ROWS

BINARY NUMBERS serve computers in logic, arithmetic and coding functions. The array of binary numbers at left under "Numeration" shows that the system, which is based on 2, represents each new power of 2 by adding a 0. The same arrangement reappears at right in the binary version of the numbers 1 through 9; it shows, for example, that 111, representing 7, can be read from the left as "one 4, one 2 and one 1." The seven-bit code (*bottom*) is widely used to accomplish the printing done by computers in issuing results and communicating with operators. On receiving pulses representing 1011001, for example, the computer would print *Y*. Columns 0 and 1 contain control characters; *BS*, for example, means "back space."

as radars, flowmeters and thermometers and must deliver its outputs directly to such effector organs as motors and radio transmitters. Still other input and output devices are demanded by the increasing speed and capacity of the computers themselves. To keep them fully employed they must be allowed to interact simultaneously with large numbers of people, most of them necessarily at remote stations. This requires telephone lines, teletypewriters and cathode-ray-tube devices. For many purposes a picture on the cathode ray tube is more useful than the half-ton of print-out paper that would deliver the underlying numerical information. Simultaneous access to the computer for many users also calls for new sophistication in programming to establish the time-sharing arrangements described in the article by R. M. Fano and F. J. Corbató [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128].

It is possible to describe at greater length the perfection and promise of the new technology of information. This discussion must go on to certain pressing questions. To put the questions negatively: Will the computer condemn us to live in an increasingly depersonalized and bureaucratized society? Will the crucial decisions of life turn on a hole punched in Column 17 of a card? Will "automation" put most of us out of work?

Experience with the computerized systems most people have so far encountered in governmental, business and educational institutions has not tended to dispel the anxiety that underlies such questions. One can ascribe the bureaucratic ways of these systems to their computers or to the greed, stupidity and other vices of the people who run them. I would argue three more direct causes: one economic, one technical and one cultural.

In the first place, computers are expensive. When a computer is first installed in an organization, the impulse of the authorities is to use the new machine to cut corners, to do the old job in the old way but more cheaply, to achieve internal economies even at the expense of external relations with citizens, customers and students. Secondly, the external memories that store the data for most large organizations are inherently inflexible. Between runs through a magnetic-tape file, for example, there is no possibility of access to the account that generates today's complaint. Finally, most practitioners in the expanding software professions were beginners; it was all they could do to get the systems going at all.

In my opinion the opportunity to cure these faults is improving steadily. Computers are cheaper, and competition between systems should soon compel more attention to the customers. (The effect is not yet noticeable at my bank.) Secondly, high-speed memory devices such as magnetic-disk files, now used as internal memories, are taking up service in external data-storage. They make access to any record possible at any time. Finally, although there are a lot of young fogies who know how things are done now and expect to see them done that way until they retire in 1996, programmers are acquiring greater confidence and virtuosity.

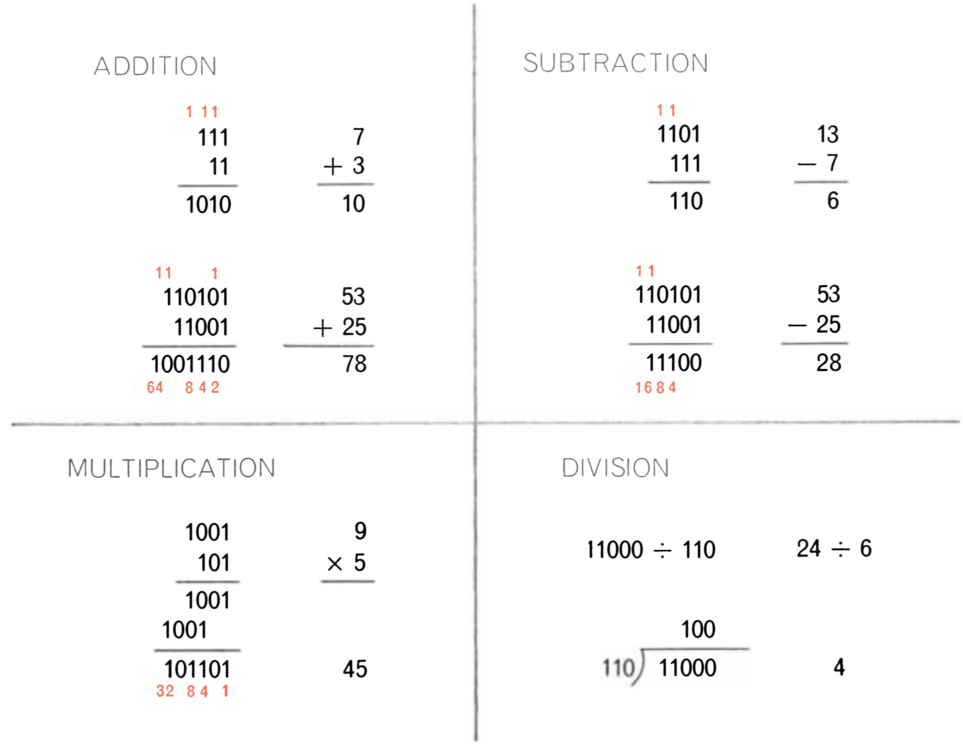
All of this should encourage the development of systems that serve the customer better without offending either his intelligence or his convenience. In particular, organizations such as schools should not have to ask people questions the answers to which are already on file.

The computer will not make its revolutionary impact, however, by doing the old bookkeeping tasks more efficiently. It is finding its way into new applications that will increase human freedom of action. No stretching of the demonstrated technology is required to envision computer consoles installed in every home and connected to public-utility computers through the telephone system. The console might consist of a typewriter keyboard and a television screen that can display text and pictures. Each subscriber will have his private file space in the computer that he can consult and alter at any time. Given the availability of such equipment, it is impossible to recite more than a small fraction of the uses to which enterprising consumers will put it. I undertake here only to sample the range of possibilities.

Everyone will have better access to the Library of Congress than the librarian himself now has. Any page will be immediately accessible, although Ben-Ami Lipetz holds that this may come later rather than sooner [see "Information Storage and Retrieval," by Ben-Ami Lipetz, page 224]. Because payment will depend on usage, all levels and kinds of taste can be provided for.

The system will serve as each person's external memory, with his messages in and out kept nicely filed and reminders displayed at designated times.

Full reports on current events, whether baseball scores, the smog index in Los Angeles or the minutes of the 178th



BINARY ARITHMETIC involves only the manipulation of 0 and 1 and hence is the basis of the extremely rapid calculating done by computers. The superscript colored numerals represent carries; subscript colored numerals show how binary numbers are read decimally.

meeting of the Korean Truce Commission, will be available for the asking.

Income tax returns will be automatically prepared on the basis of continuous, cumulative annual records of income, deductions, contributions and expenses.

With the requisite sensors and effectors installed in the household the public-utility information system will shut the windows when it rains.

The reader can write his own list of assignments. He can do so with the assurance that various entrepreneurs will try to think up new services and will advertise them. In this connection the Antitrust Division of the Department of Justice should see to it that companies set up to operate the computers are kept separate from companies that provide programs. Competition among the programmers will intensify and diversify demand on the public-utility systems. Anyone who has a new program he thinks he can sell should be free to put it in any computer in which he is willing to rent file space and to sell its services to anyone who wants to use it.

As for the conformities currently imposed by mass production, consider how the computer might facilitate the purchase of some piece of household equipment. In the first place, the computer could be asked to search the catalogues and list the alternatives available, together with appraisals from such institutions as Consumers Union. If the consumer knows how to use an automatic design system such as that described by Steven Anson Coons [see "The Uses of Computers in Technology," by Steven Anson Coons, page 176], he might design the desired equipment himself. The system will deliver not only drawings but also the findings of a simulation study that will show how well the equipment works. The consumer could also consult a designer, who will be able to render his service through the computer at less cost, together with firm estimates from prospective suppliers. With more or less elaboration, the procedures sketched here could do the paper work for the building of an entire house.

Apart from the physical construction of the public-utility information system, the full realization of these possibilities will require new advances in programming. No application illustrates the virtues and limitations of present-day programming so well as do efforts to use computers to aid teaching in elementary and secondary schools. In principle, one computer can give simultaneous individual attention to hundreds of students, each at his own console, each at a different place in the course or each concentrating on a different topic. The treatment of the student can be quite individual because the computer can remember the student's performance in every preceding session of instruction. The pace and the range of study can be entirely determined by the student's progress.

The teaching programs that have been written so far, however, put the student in a passive role. They are extremely pedantic. They have no understanding of the student's state of mind; they decide what to do next only in accordance with rather stereotyped sets of rules. As Patrick Suppes concludes, these programs do not compare too unfavorably with the performance of a teacher who has a large class [see "The Uses of Computers in Education," by Patrick Suppes, page 206]. Particularly where practice and repetition are the dominant ways of learning, the computer may even prove superior. The present programs fail in subjects that ought to cultivate the student's capacity for generating new ideas.

For the future it would be well, perhaps, to think of computers as study aids rather than teachers. The aim of the program should be to place the system under the control of the learner. He should be able to select from a list of topics the one he wants to work on; he should decide whether he prefers to read an exposition or to try to solve a problem. Best of all, he should be able to use the computer as a tool for testing his own ideas.

Reflection on the power of computer systems inevitably excites fear for the safety and integrity of the individual. In many minds the computer is the ultimate threat. It makes possible, for instance, a single national information file containing all tax, legal, security, credit, educational, medical and employment information about each and every citizen. Certainly such a file would be the source of great abuses. The files that exist today are abused. Security files, for example, have provided material for politically motivated persecutions. Credit files, to which access is wide open in the business community, have been used for purposes irrelevant to credit decisions. Accordingly it can be expected that more centralized files will facilitate even greater abuses.

On the other hand, citizens could seize the creation of centralized files as the occasion to cure existing abuses and to establish for each individual certain rights with respect to these files. Such a "bill of rights" might specify the following:

No organization, governmental or private, is allowed to maintain files that cover large numbers of people outside of the general system.

The rules governing access to the files are definite and well publicized, and the programs that enforce these rules are open to any interested party, including, for example, the American Civil Liberties Union.

An individual has the right to read his own file, to challenge certain kinds of entries in his file and to impose certain restrictions on access to his file.

Every time someone consults an individual's file this event is recorded, together with the authorization for the access.

If an organization or an individual obtains access to certain information in a file by deceit, this is a crime and a civil wrong. The injured individual may sue for invasion of privacy and be awarded damages.

At present an organization that claims to be considering extending credit to a person can learn a lot about his financial condition. In the new system no such information will be available without authorization from the person concerned. The normal form of authorization will allow no more than a yes-or-no answer to the question of whether he meets a particular definite credit criterion—whether he meets credit condition C1, for example, and can be expected to manage the installment purchase of a television set.

To establish such rights people must revise their ideas about the source and nature of their freedom. Most individual rights now recognized are based on the claim that the individual always had them; the safeguards of the law are said to be designed to prevent their infringement. Technology is advancing too fast, however, to allow such benevolent frauds to work in the future. The right to keep people from keeping files on us must first be invented, then legislated and actively enforced.

It may be supposed that, as happened with television and then color television, the enthusiasts and the well-to-do will be the first to install computer consoles in their homes. Eventually, however, everyone will consider them to be essential household equipment. People will soon become discontented with the "canned" programs available; they will want to write their own. The ability to write a computer program will become as widespread as the ability to drive a car.

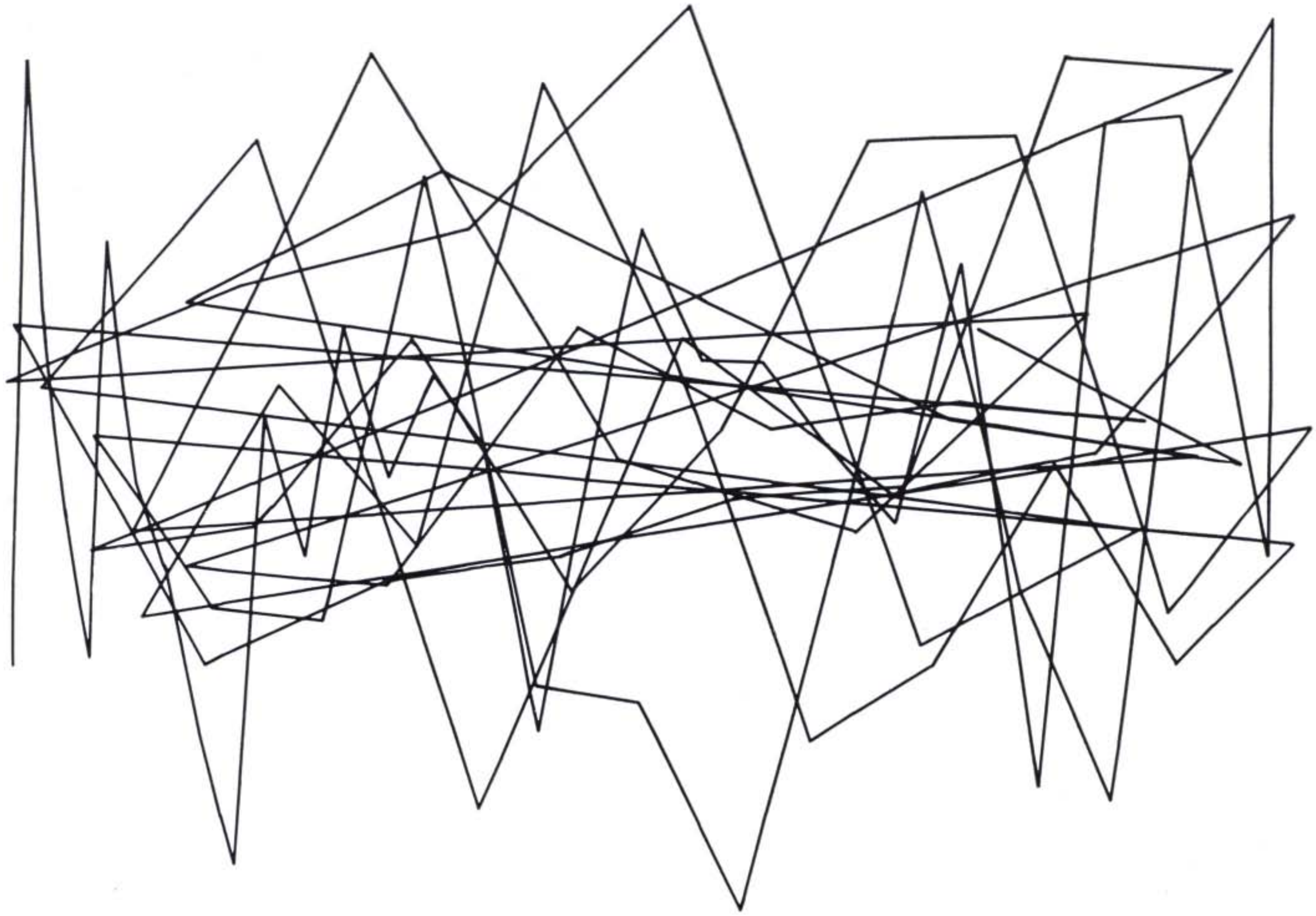
Not knowing how to program will be like living in a house full of servants and not speaking their language. Each of the canned programs will be separately useful. It will be up to the individual, however, to coordinate them for his own fullest benefit. People will find, in fact, that console control of a process leads directly to the writing of one's own programs.

At first the computer says in effect: I can do the following things for you, which do you want? You reply. Then it says: In order to do this I need the following information. You respond and the dialogue continues. After you get used to using a particular facility, the computer's questions become annoying. You know in advance what they will be and you want to give the answers without waiting for the questions. Next you want to be able to give the entire sequence of actions a name and bring forth the sequence by typing only the name. As you become bolder you will want to make a later action conditional on the results of earlier actions and to provide for the repetition of actions until a criterion is reached. You are then already programming in full generality, albeit awkwardly.

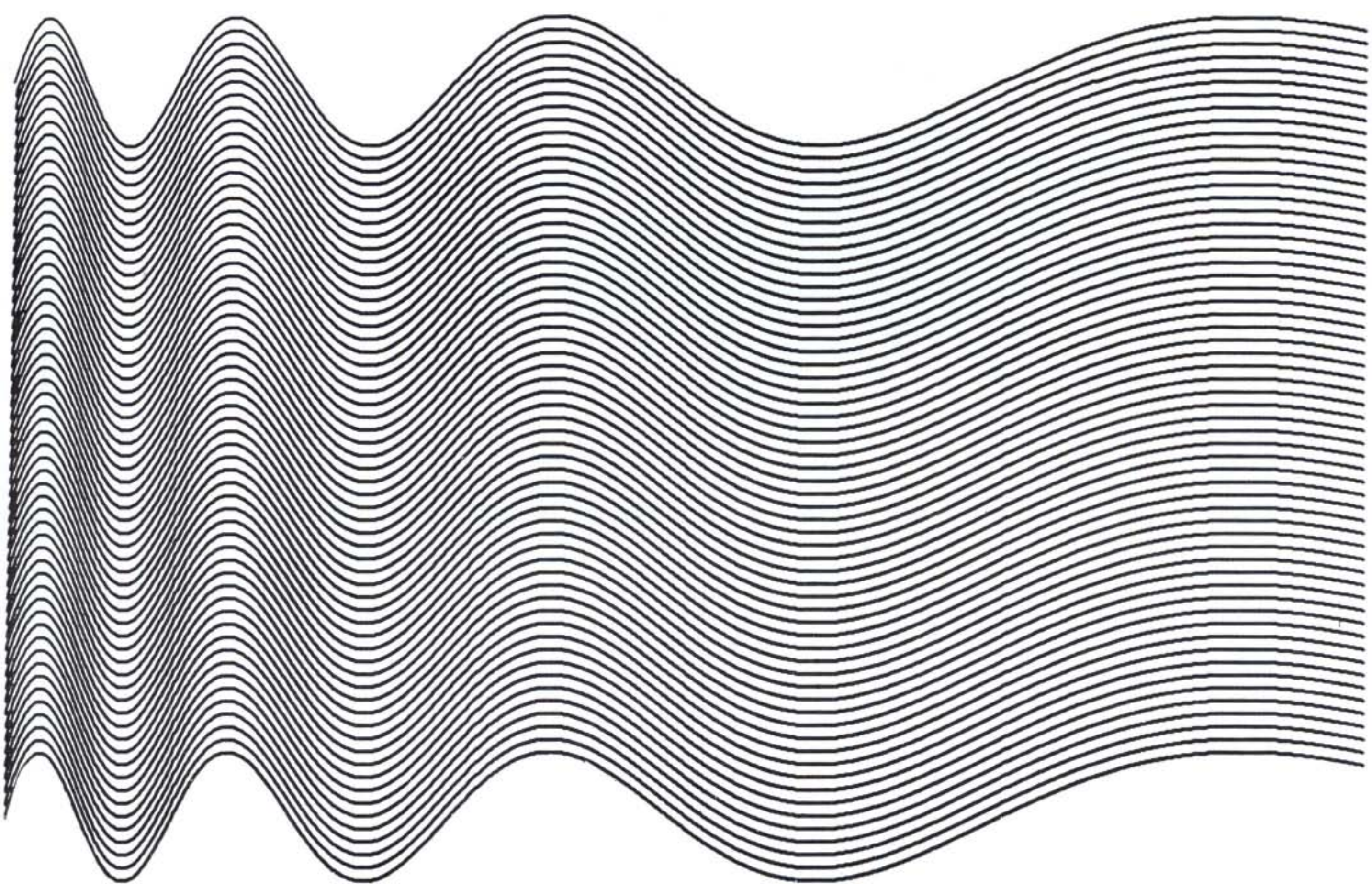
As a skill, computer programming is probably more difficult than driving a car but probably less difficult than flying an airplane. It is more difficult than arithmetic but less difficult than writing good English. It does not require long study. Many people can write simple programs after an hour or two of instruction. Some success ordinarily comes quickly, and this reward reinforces further effort. Programming is far easier to learn than a foreign language or algebra.

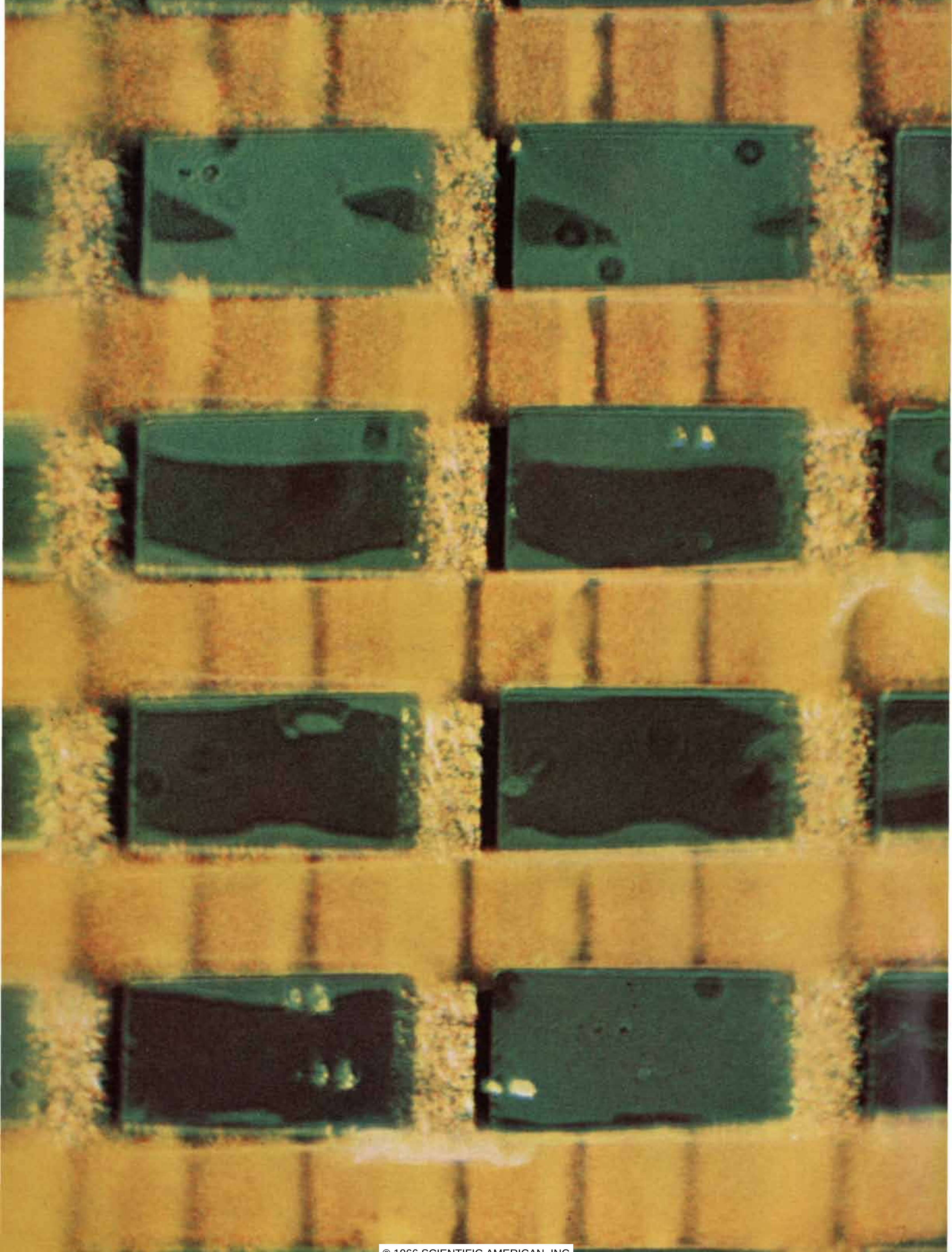
Success in writing a program to do a particular task depends more on understanding the task and less on mastery of programming technique. To program the trajectory of a rocket, for example, requires a few weeks' study of programming and a few years' study of physics.

Writing a program to carry out some activity requires that an individual make explicit what he wants. The public-utility computer will do exactly what it is told to do within limitations imposed to protect other people's interests. A person who has experienced the unexpected and sometimes unpleasant consequences of the faithful execution of his wishes is usually ready to reexamine his preferences and premises. Fortunately programs can be readily changed. As people acquire greater control over their environment by explicit programming they will discover greater self-understanding and self-reliance. Some people will enjoy this experience more than others.



COMPUTER-GENERATED ART includes two works devised by A. Michael Noll of Bell Telephone Laboratories. At top is "Gaussian-Quadratic." The end points of each line have a Gaussian random distribution vertically; the horizontal positions increase quadratically. The pattern begins at left and is "reflected" back from right. At bottom is a portion of "Ninety Parallel Sinusoids with Linearly Increasing Period." The top line was mathematically specified as such a curve; the computer then repeated the line 90 times.





COMPUTER LOGIC AND MEMORY

A large modern computer can contain nearly half a million switching elements and 10 million high-speed memory elements. They operate with the simplest of all logics: the binary logic based on 0 and 1

by David C. Evans

Electronic digital computers are made of two basic kinds of components: logic elements (often called switching elements) and memory elements. In virtually all modern computers these elements are binary, that is, the logic elements have two alternative pathways and the memory elements have two states. Accordingly all the information handled by such computers is coded in binary form. In short, the information is represented by binary symbols, stored in sets of binary memory elements and processed by binary switching elements.

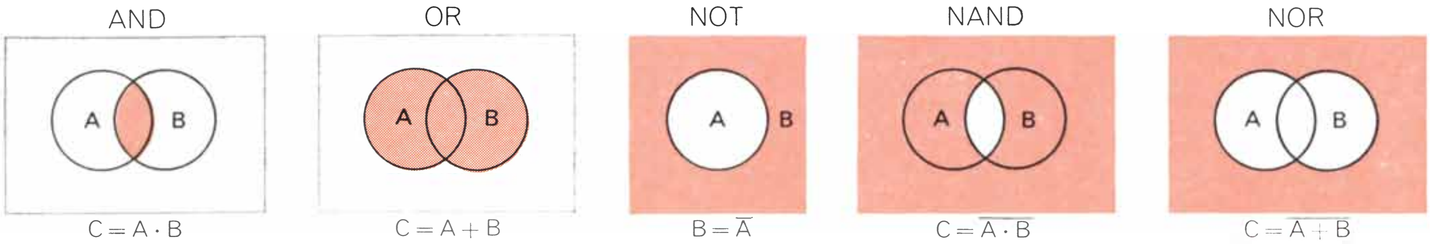
To make a digital computer it is necessary to have memory elements and a set of logic elements that is functionally complete. A set of logic elements is functionally complete if a logic circuit capable of performing any arbitrary logical function can be synthesized from elements of the set. Let us examine one such functionally complete set that contains three distinct types of circuit designated *and, or* and *not*. Such circuits can be depicted with input signals at the left and output signals at the right [*see middle illustration on next page*]. Since the logic elements are binary, each input and output is a binary variable that can have the value 0 or 1. In an electrical circuit the logical value 0 corresponds to a particular voltage or current and the logical value 1 to another voltage or current. For each symbolic circuit one can construct a "truth table," in which are listed all possible input states and the corresponding output states. Each truth table, in turn, can be represented by a Boolean statement (named for the 19th-century logician George Boole) that expresses the output of the circuit as a function of the input. Truth tables and Boolean statements are shown in the illustrations on the next page. In the case of the *and* circuit the output variable C has the value 1 if, and only if, the input variables A and B both have the value 1. In the Boolean statement the operation *and* is designated by the dot; it reads "*C* is equal to *A and B*." In the *or* circuit C has the value 1 if at least one of the input variables has the value 1. The Boolean statement is read "*C* is equal to *A or B*." The *not* circuit has for its output the logical complement of the input. Its Boolean statement is read "*B* is equal to *not A*." The *and* and *or* circuits described have only two input variables. Circuits that have a larger number of input variables are normally used.

There are a number of other functionally complete sets of logic elements. Two sets are particularly interesting because each contains only one element, in one case called *nand* (meaning "not and") and in the other case called *nor* (meaning "not or"). The bottom illustration at the left on the next page shows a symbolic representation of a two-input *nand* circuit with its truth table. Although a practical *nand* circuit is designed as an entity, it is evident that it can be realized by an *and* and a *not* circuit. The reader can easily devise *and, or* and *not* circuits from *nand* circuits to demonstrate to himself that the *nand* circuit is also functionally complete.

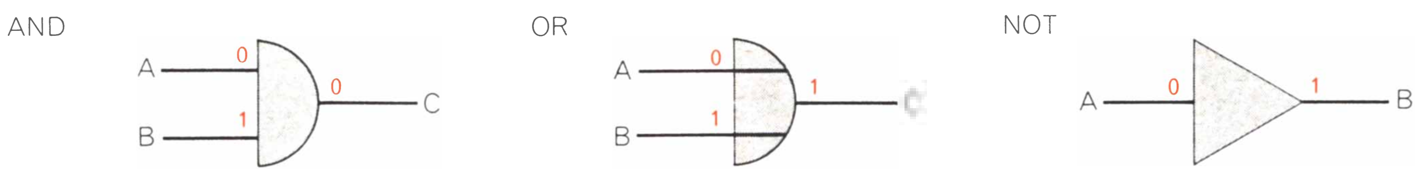
With *and* and *not* circuits it is not difficult to construct a decoding circuit that will translate binary digits into decimal digits. The top illustration on page 78 shows such a circuit and its truth table. The decimal digits are each represented by a four-digit binary code (A_0, A_1, A_2, A_3). In the decoding circuit, which yields the first four decimal digits, the input signals A_0, A_1, A_2, A_3 are applied. The signal at each of the numbered outputs is 0 unless the input code is the code for one of the numbered outputs, in which case the signal at that output is 1.

The circuits that store information in a computer can be divided into two classes: registers and memory circuits. Registers are combined with logic circuits to build up the arithmetic, control and other information-processing parts of the computer. The information stored in registers represents the instantaneous state of the processing part of the computing system. The term "memory" is commonly reserved for those parts of a computer that make possible the general storage of information, such as the instructions of a program, the information fed into the program and the results of computations. Memory devices for such storage purposes will be discussed later in this article.

THIN-FILM MEMORY (*opposite page*) consists of an array of rectangular storage elements, only four millionths of an inch thick, deposited on a thin glass sheet. The rectangles are oriented in one of two magnetic states, corresponding to 0 or 1, when electric currents are passed through conductors (*vertical stripes*) printed on the back of the glass. The films can be switched in a few billionths of a second. The states can be made visible if the thin-film surface is illuminated with plane-polarized light and photographed through a suitably adjusted polarizing filter. The magnetic film causes a slight rotation in the plane of polarization of the reflected light. Here the predominantly dark rectangles are in the 1 state; the light rectangles are in the 0 state. The photograph is a 100-diameter enlargement of a thin-film memory developed by the Burroughs Corporation for use in its newest computers.



VENN DIAGRAMS use circles to symbolize various logic concepts and relations. Circles represent statements that can be either true or false; they are placed in a universe, or field, that represents all other statements. The logical relation *and* is represented by the shaded area where two circles overlap. This area, *C*, is "true" only if both circles, *A* and *B*, are true; it is "false" if either *A* or *B* or both are false. The logical relation *or* (the "inclusive or") is represented by shading the entire area within both circles. This area, *C*, is true when either *A* or *B* or both are true. *Not* is represented by a circle, *A*, surrounded by a universe, *B*, which is not *A*. The equations below the Venn diagrams are Boolean statements. The dot in the *and* statement stands for "and." The plus sign in the *or* statement stands for "or." The $\overline{A}$ in the *not* statement signifies "not *A*." *Nand* and *nor* stand respectively for "not and" and "not or," as is made clear in the shading of their Venn diagrams. Such diagrams are named for John Venn, a 19th-century English logician.



$C = A \cdot B$

A	B	C
0	0	0
0	1	0
1	1	1
1	0	0

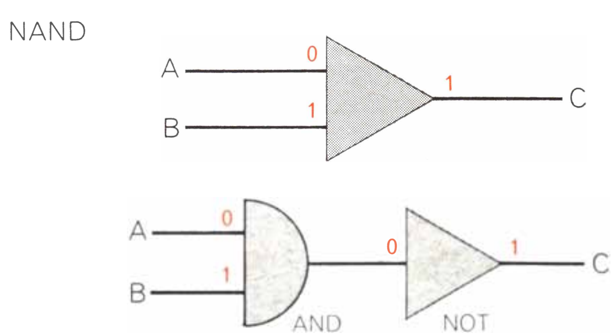
$C = A + B$

A	B	C
0	0	0
0	1	1
1	1	1
1	0	1

$B = \overline{A}$

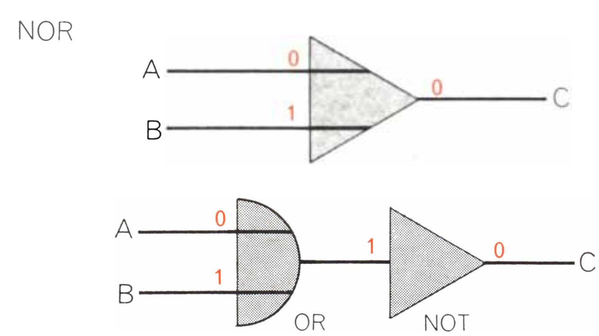
A	B
0	1
1	0

AND, OR AND *NOT* constitute a set of binary logic elements that is functionally complete. The three symbols represent circuits that can carry out each of these logic functions. Input signals, either 0 or 1, enter the circuits at the left; outputs leave at the right (*colored digits are examples*). Below each circuit is a "truth table" that lists all possible input states and corresponding output states.



$C = \overline{A \cdot B}$

A	B	C
0	0	1
0	1	1
1	1	0
1	0	1



$C = \overline{A + B}$

A	B	C
0	0	1
0	1	0
1	1	0
1	0	0

NAND CIRCUIT, which contains only one logic element, is functionally complete; it can do everything that *and*, *or* and *not* circuits can perform collectively. The two-input *nand* circuit symbolized at top is equivalent to the combined *and* and *not* circuit. Outputs of the *nand* truth table are opposite to those of the *and* table.

NOR CIRCUIT is also functionally complete. The two-input *nor* circuit symbolized at top is equivalent to the combined *or* and *not* circuit shown immediately below. The *nor* truth table is the converse of the *or* table. Electronic embodiment of a circuit that can serve as either *nand* or *nor* appears on the opposite page.

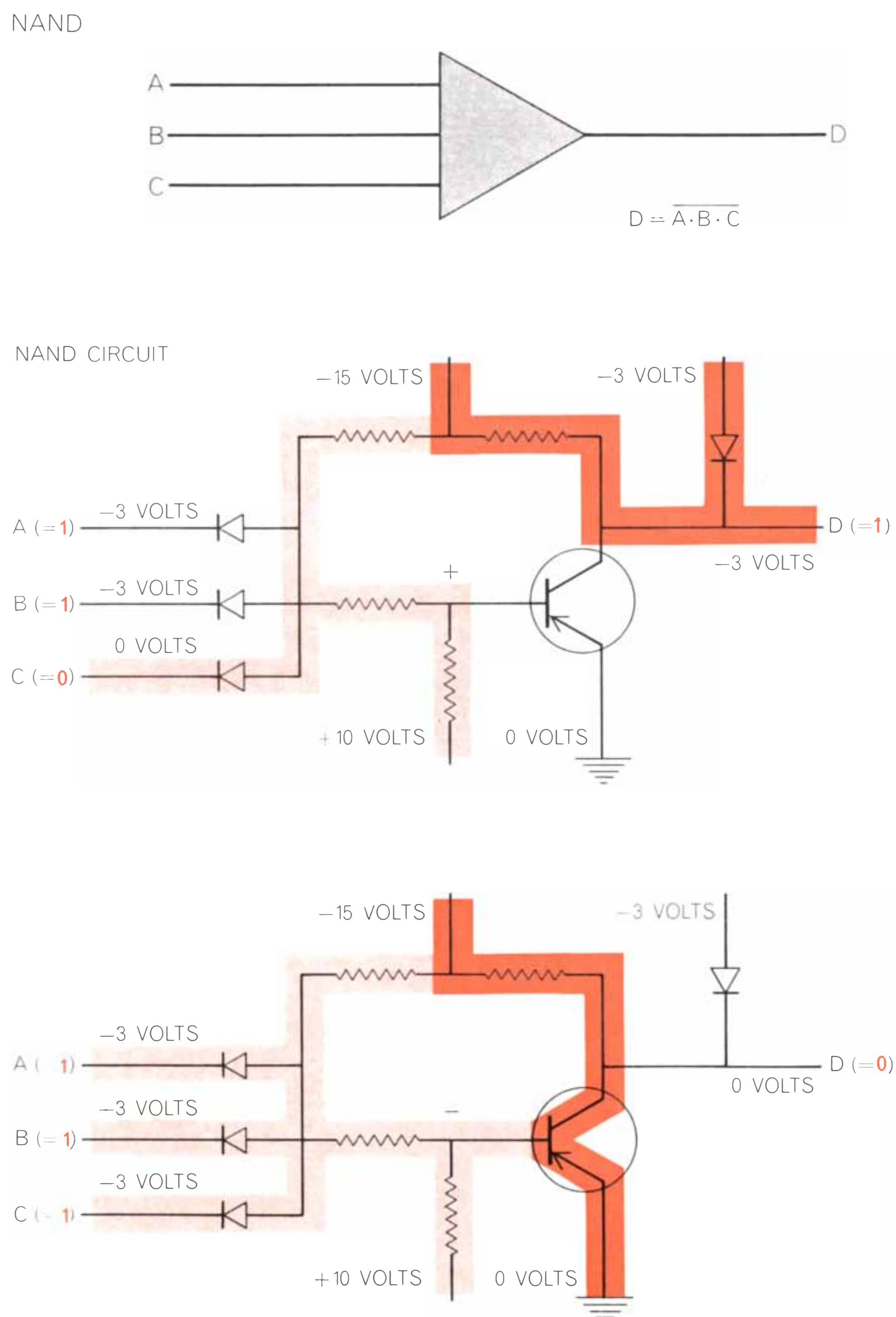
Registers are usually made up of one-bit storage circuits called flip-flops. A typical flip-flop circuit, called a set-reset flip-flop, has four terminals [*see bottom illustration on next page*]. It is convenient to refer to such a flip-flop by giving it the name of the variable it happens to store; thus a flip-flop for storing the variable *A* will be named *A*. If the inputs to the terminals *S* and *R* are 0, the flip-flop will be in one of two states. If *A* has the value 1, it is in the set state; if it has the value 0, it is in the reset state. It can be switched to the set state by applying a 1 signal to the *S* terminal and switched to the reset state by applying a 1 to the *R* terminal. The application of 1's to the *S* and *R* terminals at the same time will not yield a predictable result. The flip-flop can therefore be regarded as remembering the most recent input state.

Memories for general storage could be made up of logic circuits and flip-flops, but for practical reasons this is not done. A memory so constructed would be large and expensive and would require much power; moreover, the stored information would be lost if the power were turned off.

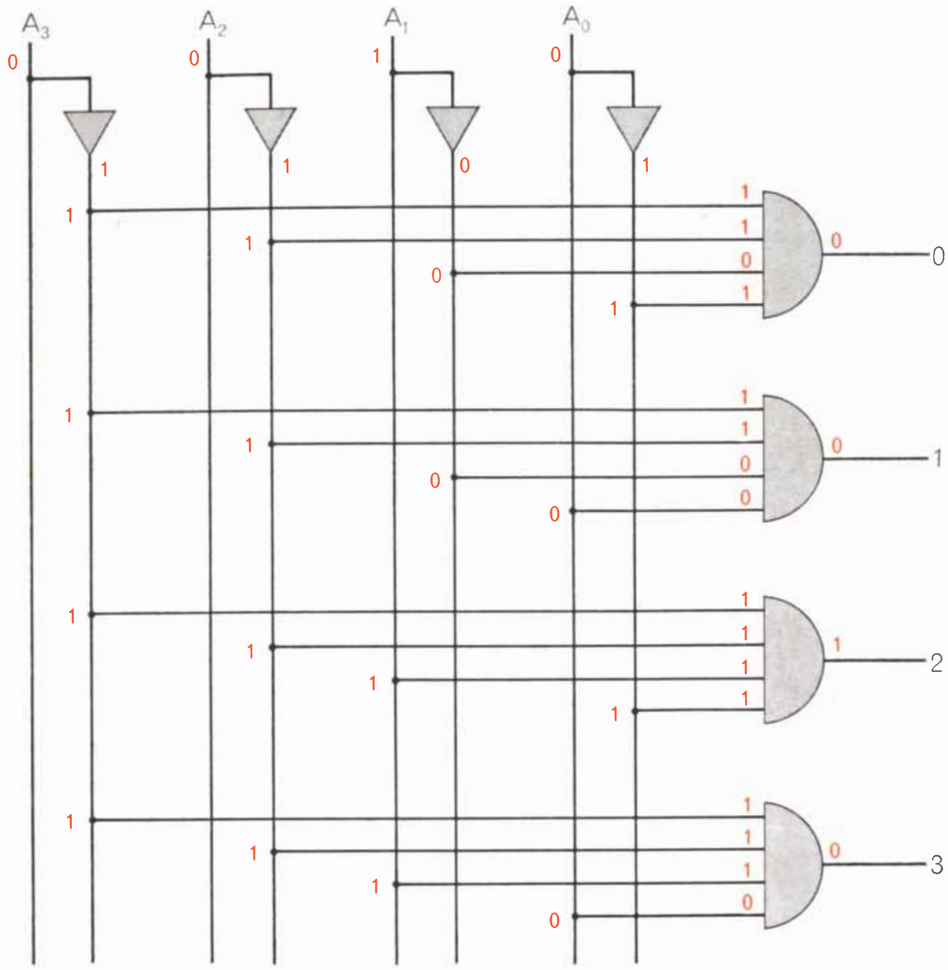
We are now ready to consider how logic circuits and registers can be combined to perform elementary arithmetical operations. The upper illustration on page 79 includes a truth table describing one-digit binary addition. The inputs to the adder are the binary digits *X* and *Y*, together with the "input carry" C_{i-1}. The outputs are the sum digit S and the "carry out" C_i. Also illustrated is an implementation of the binary adder using *and*, *or* and *not* logic elements. A logic circuit such as this binary adder, which contains only switching elements and no storage circuits, is called a combinatorial circuit.

In a computer employing binary arithmetic the arithmetic unit may have to process numbers consisting of 60 or more digits in order to produce results with the desired precision. (A computer able to handle 60-digit numbers is said to have 60 bits of precision.) Numbers of such length can be added in two general ways. One way is to use an adder for each digit; the other is to use a single "serial" adder and process the digits sequentially. When an adder is used for each digit, the assembly is called a parallel adder. The lower illustration on page 79 shows a four-digit parallel adder. The inputs for this adder are two four-digit binary numbers: $X_3\, X_2\, X_1\, X_0$ and $Y_3\, Y_2\, Y_1\, Y_0$. The adder produces the five binary-digit sum $S_4\, S_3\, S_2\, S_1\, S_0$. This four-digit adder is also a combinatorial circuit. The *X* and *Y* inputs to the parallel adder can be provided by two four-bit registers of four flip-flops each. The inputs are all provided at the same time. The sum can be stored in a five-bit register that has previously had all its stages reset to 0.

For the serial adder we need a means of delivering the digits of the inputs to the adder in sequence and of storing the sum digits in sequence. To implement these requirements special registers that have the ability to shift information from one stage to the next are employed; such a register is called a shift register. Each of the three shift registers of a serial binary adder has an input from the terminal called SHIFT [*see bottom illustration on page 80*]. Normal-

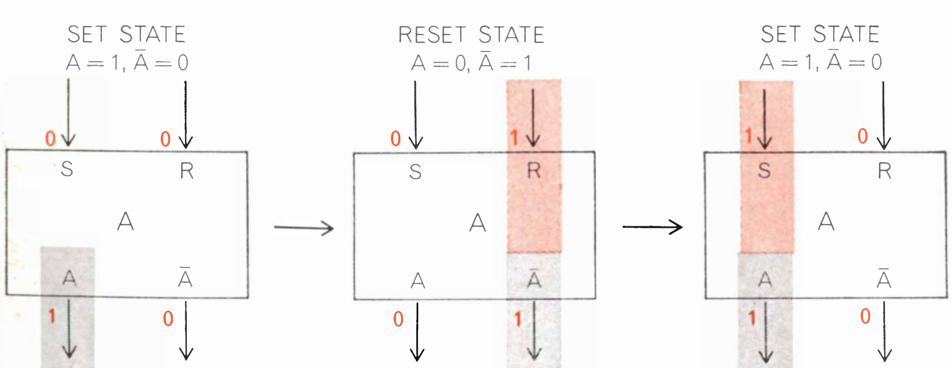


ELECTRONIC EMBODIMENT OF *NAND* CIRCUIT contains four diodes (*triangular shapes*), four resistors (*zigzags*) and one transistor (*inside circle*). The symbol for this three-input *nand* circuit and its Boolean statement appear at the top. In the circuit the dark color represents the flow of large current that is switched to produce the output, 0 or 1, depending on the flow of small current (*light color*), which is controlled by the input voltages. Current flow is shown for two different inputs: 1, 1, 0 and 1, 1, 1. By reversing the choice of voltage the *nand* circuit shown here acts as a *nor* circuit. Such circuits can be designed in many ways.



DECIMAL	BINARY			
	A_3	A_2	A_1	A_0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

CONVERSION OF BINARY to decimal digits is accomplished by this circuit, made up of four *not* circuits and four *and* circuits. The truth table at left shows the binary equivalent for the decimal digits from 0 to 9. To show the principle involved in decoding binary digits, the circuit carries the decoding only as far as decimal digit 3. The signal at each of the numbered outputs is 0 unless all the inputs are 1. In the example this is true for the third *and* circuit from the top, labeled 2. Thus the binary digits 0010 are decoded to yield the decimal digit 2.



TYPICAL ONE-BIT STORAGE ELEMENT is represented by a "set-reset flip-flop." The one shown here is given the name *A* because it stores the variable *A*. A flip-flop "remembers" the most recent input state. If *A* has the value 1, it is in the set state; if *A* has the value 0, it is in the reset state. Applying a 1 to the *S* terminal yields the set state; applying a 1 to the *R* terminal yields the reset state. Flip-flops provide the transient memory in a computer.

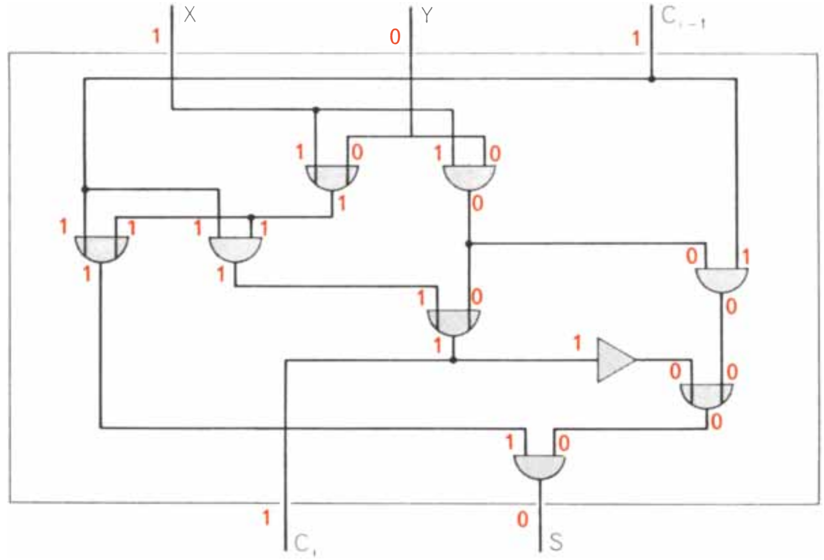
ly the SHIFT signal has the value 0, but when it is desired to shift the three registers, the SHIFT signal is given the value 1 for a brief period, causing the registers to shift their contents one bit to the right. As in the case of the parallel adder, the serial adder can add one group of binary digits (such as X_3 X_2 X_1 X_0) to another group (such as Y_3 Y_2 Y_1 Y_0). At the first command to shift, the serial adder stores the sum of the first pair of digits (X_0 and Y_0); at the second command to shift, it stores the sum of the second pair of digits (X_1 and Y_1), and so on. The carry-out (C_i) of each addition is passed along at each command to shift.

Registers are needed for both serial and parallel adders. For the serial adder the registers must be shift registers and only a one-digit binary adder is required. For the parallel adder a binary adder is required for each bit of precision, that is, for each pair of X and Y inputs. The parallel adder is simply a large combinatorial circuit. The serial adder includes the binary adder, a flip-flop (known in this case as the C flip-flop) and associated circuitry. It is not a combinatorial circuit because its output (S) is not merely a function of the immediate inputs (X and Y); it is also a function of the internal state as represented by the value stored in the C flip-flop. Circuits in which the output is not only a function of the immediate inputs but also a function of the circuit's history as represented by its internal state are called sequential circuits. Such circuits are fundamental to the design of computers. Multiplication, for example, is usually implemented by a sequential circuit that repetitively uses an adder circuit.

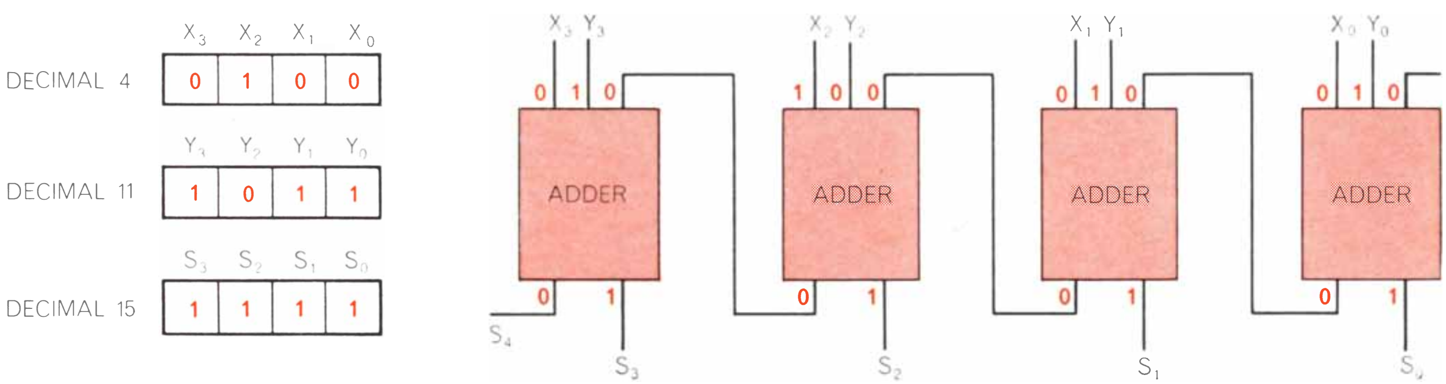
For most of the period during which computers have evolved, the limiting factor in their design and cost has been memory. The speed of computers has been restricted by the time required to store and retrieve information. The cost of computers has been determined by the information-storage capacity of the memory. As a result much effort has been devoted to the development and improvement of memory devices.

A typical memory, which I have previously described as an array of registers of uniform size, is characterized by word length, storage capacity and access time. Each register in a memory is called a word; its size is expressed in bits and typically is in the range of 12 to 72 bits. The total storage capacity of a memory can be expressed in bits

C_{i-1}	X	Y	C_i	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1



BINARY ADDER CIRCUIT (*right*) can add two one-digit binary numbers. It is made up of *and*, *or* and *not* logic elements. Because the adder will usually be one of several linked in parallel (*see illustration below*) it must also be able to accept a digit known as the input carry (C_{i-1}) produced by an adder immediately to its right. The truth table (*left*) shows the "carry-out" (C_i) and the sum digit (S) for all combinations of three inputs. In the example the inputs are 1, 0 and 1. This is known as a combinatorial circuit.



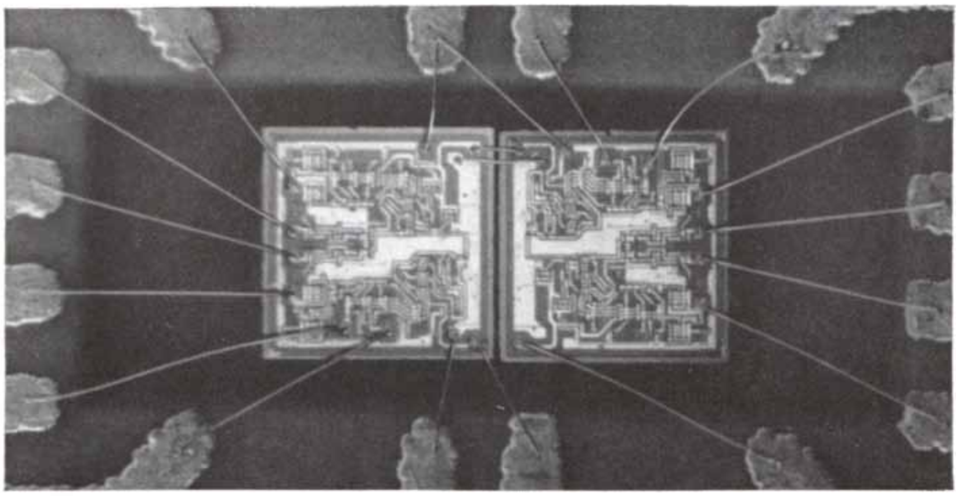
FOUR-DIGIT PARALLEL ADDER consists of four one-digit binary adders like the one shown at the top of the page. In a computer, registers (*not shown*) would be needed to supply the input signals and to store the output signals. In the example illustrated here the binary number 0100 (decimal 4) is being added to 1011 (decimal 11). The sum is the binary number 1111 (decimal 15).

but is more often expressed in words; depending on various factors, which will be examined below, the storage capacity can vary from 100 words to billions of words. The time required to store (write) or retrieve (read) a specified word of information is called the access time; it can range from a fraction of a microsecond to several seconds or minutes.

Access to a particular word in a memory is achieved by means of an addressing scheme. There are two classes of addressing schemes: "structure-addressing" and "content-addressing." In the first, which is the more common, each word is given a number by which it is identified; this number is called its address. Access to a particular word of a memory is achieved by specifying the address as a binary-coded number. In content-addressing, access is determined by the content of the word being sought. For example, each word of a content-addressed memory might contain a person's name and certain information about him (such as his bank balance or his airline reservation); access to that information would be achieved by presenting the person's name to the memory. The internal logic of the memory would locate the word containing the specified name and deliver the name and the associated information as an output. Since most memories are structurally addressed, no further consideration will be given to content-addressing.

Among the various memory designs there is a wide range of compromises among cost, capacity and access time [*see top illustration on page* 82]. Most memories fall into one of three access categories: random, periodic or sequential. In random-access memories the access time is independent of the sequence in which words are entered or extracted. Memories with short random-access times are the most desirable but also the most costly per bit of storage capacity. Magnetic-core devices are the most widely used random-access memories. An example of a memory device that provides periodic access is the magnetic drum, in which information is recorded on the circumference of a cylinder that rotates at a constant rate. Sequentially located words may be read at a high rate as they pass the sensing position. The maximum access time is one revolution of the drum, and the average access time to randomly selected words is half a drum revolution. The most common sequential memories—used when neither random nor periodic access is required—are provided by reels of magnetic tape. To run a typical 2,400-foot reel of tape containing 50 million bits of information past a reading head can take several minutes.

Since magnetic materials, in one form or another, supply the principal

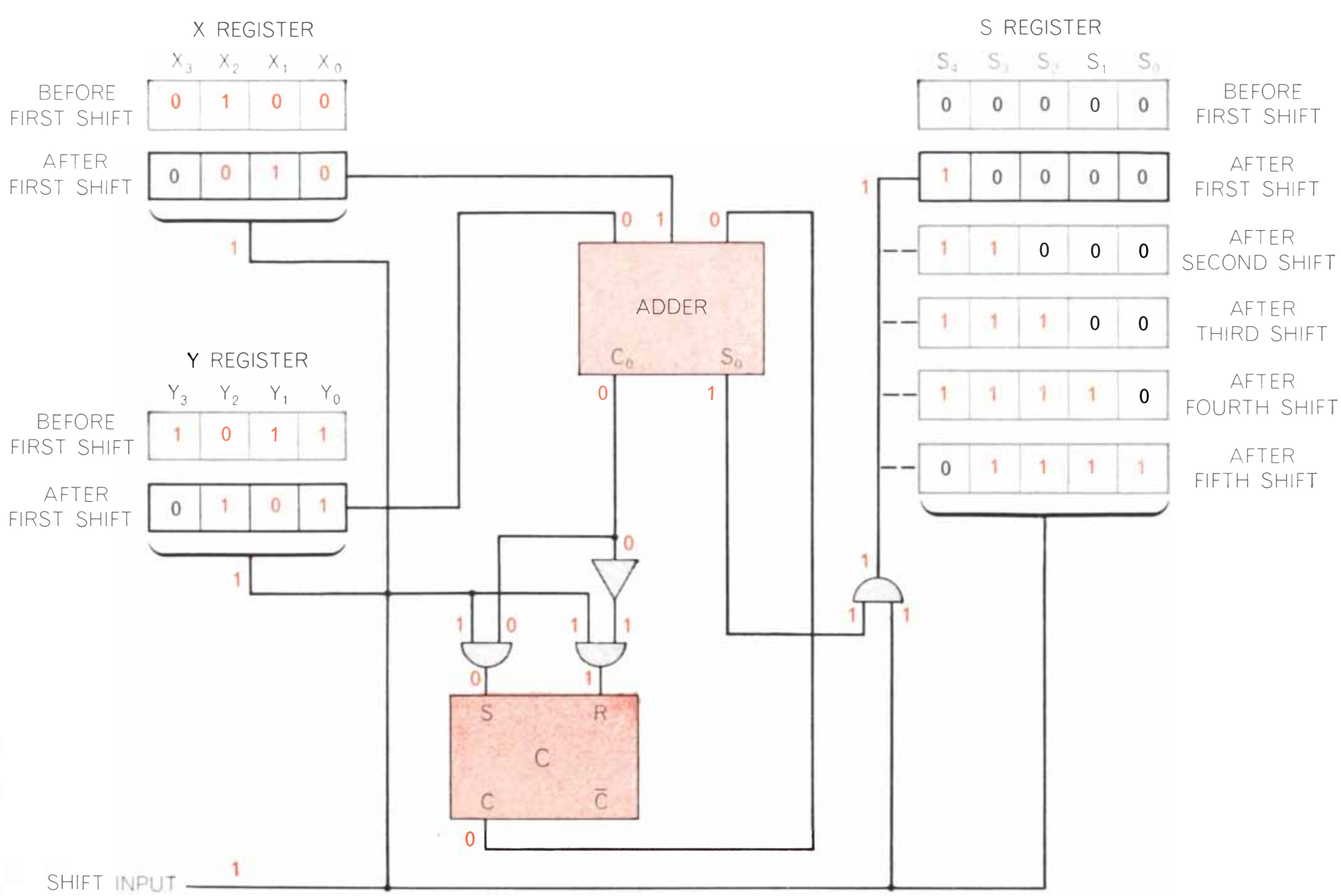


ACTUAL FOUR-DIGIT PARALLEL ADDER can be produced by linking two monolithic integrated circuits; each chip measures only 60 mils (.06 inch) on a side. This adder made by Texas Instruments Incorporated contains the equivalent of 166 discrete components.

storage medium in computers, I shall describe magnetic memories somewhat more fully. The high-speed random-access memory in a typical computer is generally provided by a three-dimensional array of about a million tiny magnetic cores, or rings, each of which can store one bit of information. The cores are threaded on a network of fine wires that provide the means for changing the magnetic polarity of the cores; the polarity determines whether a particular core stores a 1 or a 0. The cores are made of ferrite, a ferromagnetic ceramic. Highly automatic methods have been devised for forming, firing, testing and assembling the cores into memory arrays. In early magnetic-core memories the cores had an outside diameter of about a twelfth of an inch and cost about $1 per bit of storage capacity. The cycle time of these memories (the minimum time from the beginning of one access cycle to the beginning of the next) was in the range of 10 to 20 microseconds.

As the art has developed, the size of the cores has decreased, the cycle time has decreased and the maximum capacity has increased. The cores in most contemporary computers have a diameter of a twentieth of an inch; cycle times are between .75 microsecond and two microseconds. The fastest core memories have cores less than a fiftieth of an inch in diameter and cycle times of less than 500 nanoseconds (half a microsecond).

The essential requirement of a material for a random-access magnetic memory is a particular magnetic characteristic that allows a single element of



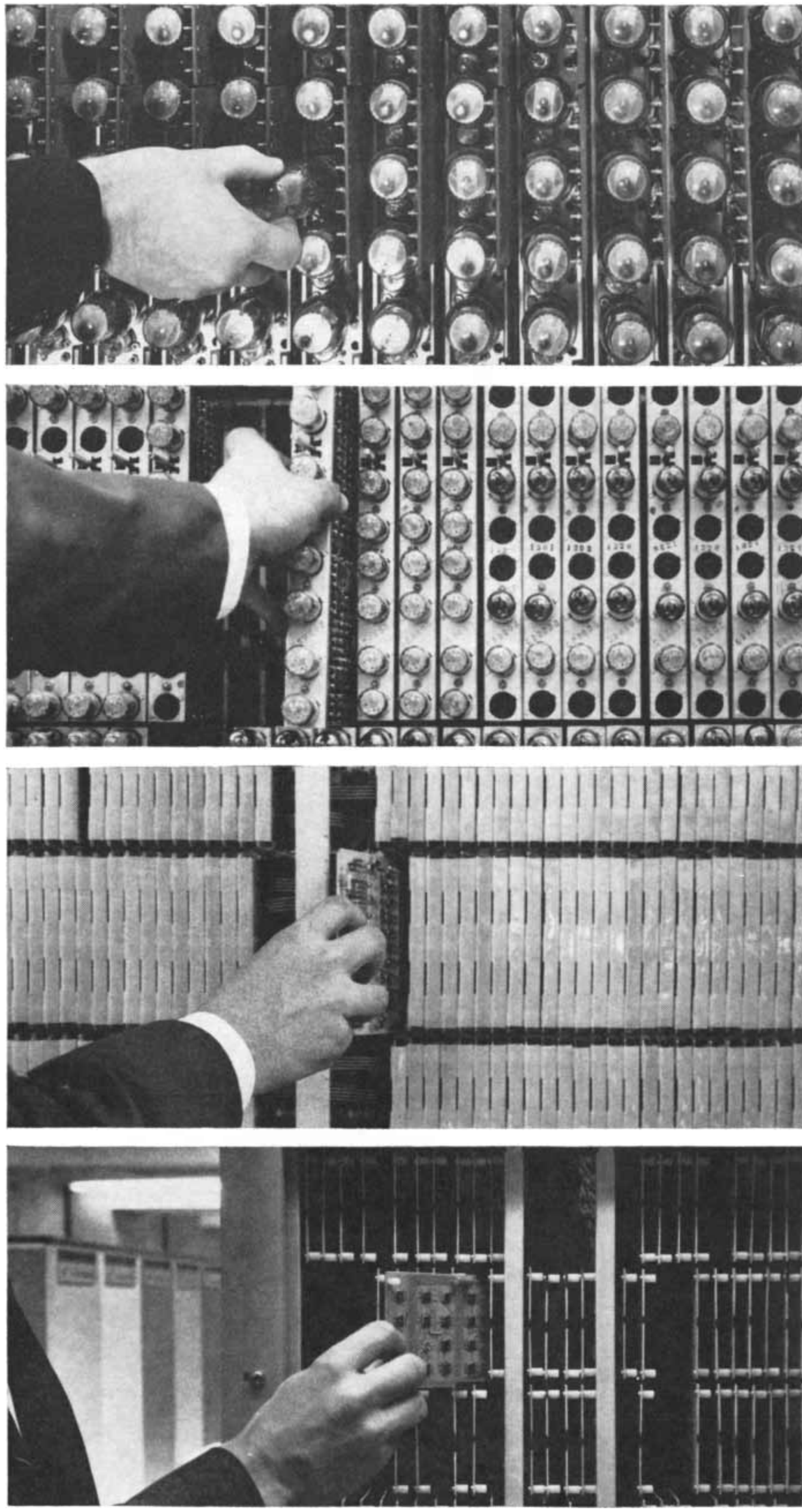
FOUR-DIGIT SERIAL ADDER uses only one adder like the one shown at the top of the preceding page but requires three shift registers and a flip-flop to pass along the carry-out of each addition. Each register has an input from the terminal called SHIFT. At the shift signal each register shifts its contents one bit to the right. Simultaneously the digits shifted out of the X and Y registers enter the adder, together with the input-carry from the C flip-flop. Five shift signals are needed to add two four-digit binary numbers.

a large array of elements of the material to be stably magnetized in either of two directions. Early in the 1950's it was discovered that certain thin metallic films also have this characteristic [*see illustration on page 74*]. The constant dream of computer designers since this discovery was made has been the development of a practical large-capacity memory that can be constructed directly from bulk materials without fabrication, test or assembly of discrete components for individual bits. Many geometries for thin-film memories, including flat films and films deposited on wires or glass rods, have been devised. Some film memories are in service and many more will be used in the future. It is anticipated that there will be dramatic reductions in the cost of random-access memories over the next few years.

In another widely used memory technology a thin film of magnetic material is deposited on some surface such as a plastic tape or card, or a metallic drum or disk. This magnetic surface is moved with respect to a head that can produce or detect patterns of magnetization in the magnetic film; the patterns are of course coded to represent the binary digits 1 and 0. The film for magnetic recording usually consists of finely ground iron oxides bonded together and to the surface by a small amount of organic binder. For magnetic drums and disks the magnetic medium often consists of a metallic film of a nickel-cobalt alloy.

Magnetic tape about a thousandth of an inch thick, half an inch wide and up to 2,400 feet long per reel has provided the main bulk information store for many years. Tape systems have reached a high state of development: they are able to transport the tape past the head at a rate of more than 100 inches per second and to start or stop the tape in a few milliseconds. Six or eight bits are usually written across the width of the tape; it is common for 800 of these six-bit or eight-bit groups to be written per inch along the tape. A current trend in information-processing systems is toward using tape for dead storage or for transporting data from one location to another. Magnetic recording devices with shorter random-access times are taking over the function of active file storage.

Storage devices with a capacity of a few hundred million words and an access time of a few seconds or less are just beginning to be delivered. These devices employ a number of magnetic



EVOLUTION OF CIRCUITS is reflected in these close-ups showing the central processing units in four generations of computers. UNIVAC I (*top*), the first large commercial electronic computer, used vacuum-tube logic circuits. The first model was delivered to the Bureau of the Census in 1951. International Business Machines' Model 704 (*second from top*) was a widely used large-scale vacuum-tube computer with a magnetic-core memory. The first 704 was installed in late 1955. In 1963 IBM delivered the first 7040 (*third from top*), a typical transistorized computer using discrete components. The Spectra 70/45 (*bottom*), recently delivered by the Radio Corporation of America, represents the latest generation. It uses monolithic integrated circuits similar to the one shown at the top of the opposite page.

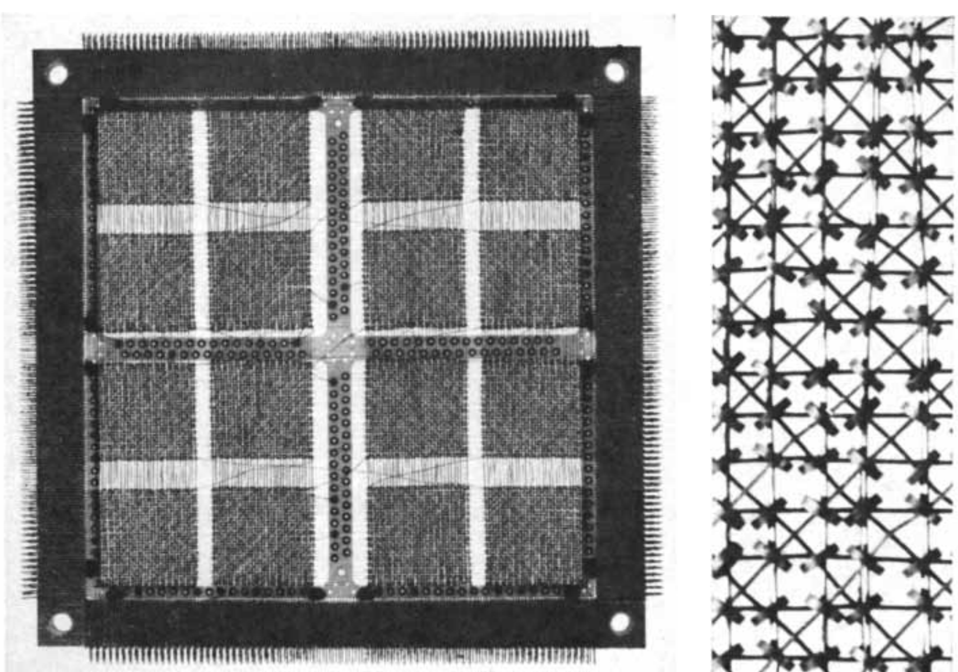
TYPE OF MEMORY	RANDOM ACCESS TIME (MICROSECONDS)	INFORMATION TRANSFER RATE (BITS PER SECOND)	CAPACITY (BITS)	COST (DOLLARS PER BIT)
INTEGRATED CIRCUIT	$10^{-2} - 10^{-1}$	$10^{9} - 10^{10}$	$10^{3} - 10^{4}$	10
TYPICAL CORE OR FILM	1	10^{8}	10^{6}	10^{-1}
LARGE SLOW CORE	10	10^{7}	10^{7}	10^{-2}
MAGNETIC DRUM	10^{4}	10^{7}	10^{7}	10^{-3}
TAPE LOOP OR CARD	10^{6}	10^{6}	10^{9}	10^{-4}
PHOTOGRAPHIC	10^{7}	10^{6}	10^{12}	10^{-6}

COMPARISON OF MEMORY SYSTEMS shows a range of roughly a billion to one in access time and capacity and about 10 million to one in cost per bit. The spread in the rate of information transfer is smaller: about 10,000 to one from the fastest memories to the slowest. Integrated circuit memories (similar to logic circuits) and photographic memories (for digital storage) are just appearing.

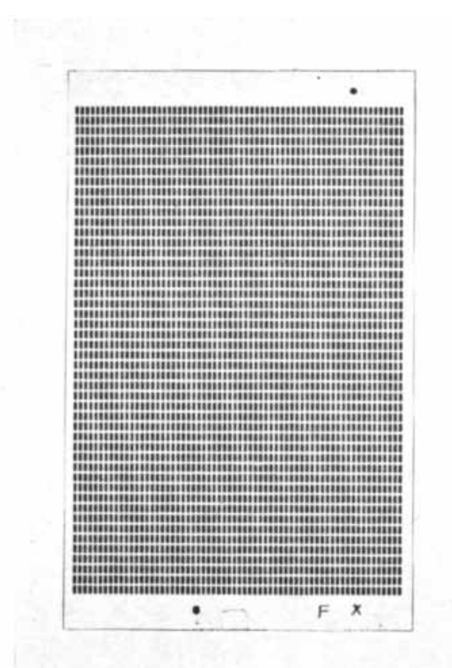
cards or tape loops handled by various ingenious mechanisms [*see illustration on page 85*].

In memory systems that use magnetic drums and disks rotating at high speed, the heads for reading and writing information are spaced a fraction of a thousandth of an inch from the surface. The surface velocity is about 1,000 or 2,000 inches per second. In early drum systems severe mechanical and thermal problems were encountered in maintaining the spacing between the heads and the recording surface. In recent years a spectacular improvement in performance and reliability has been achieved by the use of flying heads, which maintain their spacing from the magnetic surface by "flying" on the boundary layer of air that rotates with the surface of the drum or disk. One modern drum memory has a capacity of 262,000 words and rotates at 7,200 revolutions per minute; it has a random-access time of about four milliseconds and an information-transfer rate of 11.2 million bits per second.

Magnetic information storage is meeting competition from other memory technologies in two areas: where fairly small stores of information must be accessible in the shortest possible time and where ultralarge stores must be accessible in a matter of seconds. For the first task, which today is usually performed by magnetic cores and thin



MAGNETIC-CORE MEMORY has been the standard high-speed memory in computers for many years. A typical core memory plane is shown two-thirds actual size at the left; a portion of the plane is enlarged about 10 diameters at the right. This example, made by Fabri-Tek Incorporated, contains 16,384 ferrite cores, each a fiftieth of an inch in diameter.



THIN-FILM MEMORY made by Burroughs, which operates even faster than magnetic-core memories, is shown here actual size. An enlargement in color appears on page 74.

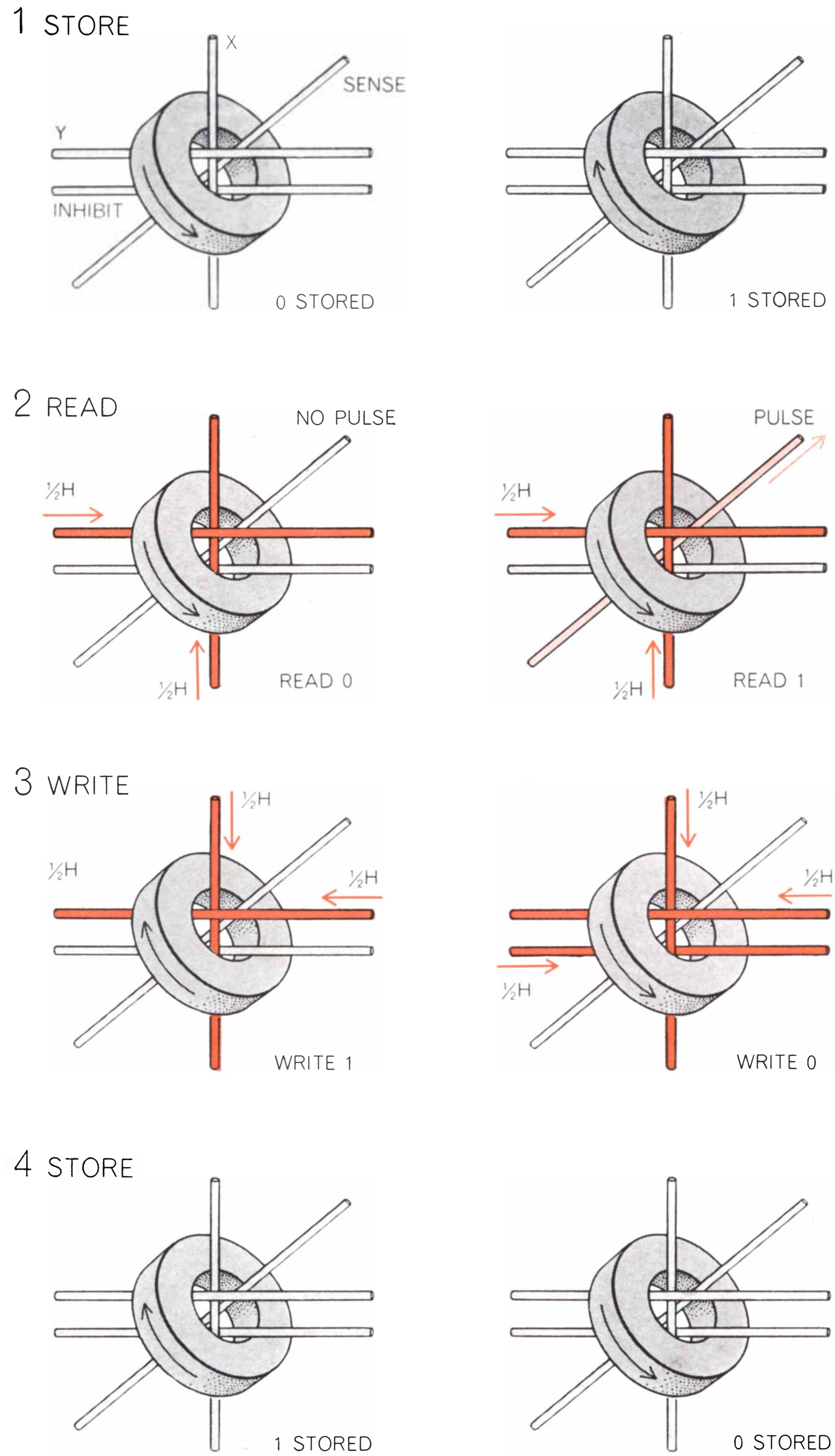
films, one can now obtain memories fabricated by the same techniques used to produce monolithic integrated circuits [see "Microelectronics," by William C. Hittinger and Morgan Sparks; SCIENTIFIC AMERICAN, November, 1965]. Such circuits, resembling flip-flops, can be built up from tiny transistors and resistors; scores of such elements can be packed into an area no more than a tenth of an inch square [*see bottom left of illustration on page* 85]. A memory of this kind can store about 100 words and have a random-access time of 100 nanoseconds. Although the present cost of such memories is a few dollars per bit, the cost will probably decline to a few cents per bit by 1970. Integrated-circuit memories have the drawback that power is continuously dissipated by each element (unlike magnetic elements) whether it is actively being read (or altered) or not.

For very-high-volume storage and moderately fast access time, magnetic devices are being challenged by high-resolution photography. In these systems bits are recorded as densely packed dots on transparent cards or short strips of photographic film. During the next year or so several such systems will go into service; each will have a capacity of 10^{11} or 10^{12} bits and a maximum access time of a few seconds.

To combine rapid average access time and large storage capacity at a minimum cost to the user, computer designers have recently introduced the concept of the "virtual memory." Such a memory simulates a single large, fast random-access memory by providing a hierarchy of memories with a control mechanism that moves information up and down in the hierarchy, using a strategy designed to minimize average access time.

The logic and main memory of a very large modern computer contains nearly half a million transistors and a somewhat larger number of resistors and other electrical components, in addition to 10 million magnetic cores. In such a machine—or even in a smaller one with a tenth or a hundredth of this number of components—the matters of packaging, interconnection and reliability present very serious design problems.

The active circuit elements in early electronic computers were vacuum tubes. These computers encountered three major problems. First, the rate at which tubes failed was so high that in large computers the ratio of nonproduc-



OPERATION OF MAGNETIC-CORE MEMORY involves switching the direction of magnetization, or polarity, of a ferrite core between two positions 180 degrees apart. One position is selected to represent 0, the other to represent 1. "Reading" and "writing" signals are carried on two wires (*X and Y*), each of which carries only half of the current (*½H*) needed to change the core's direction of polarization. During the reading cycle the direction of current flow is selected so that the pulses reverse the polarity of a core that is storing a 1, with the result that a voltage pulse signifying 1 (*light color*) is created in the "sense" wire. No pulse emanates from a core that is storing a 0. During the writing cycle the flow in the *X* and *Y* wires is reversed. This reverses the polarity of the core and writes 1 unless an opposing current is coincidentally passed through an "inhibit" wire, in which case the core polarity remains in the 0 position. A typical memory will contain a million cores.

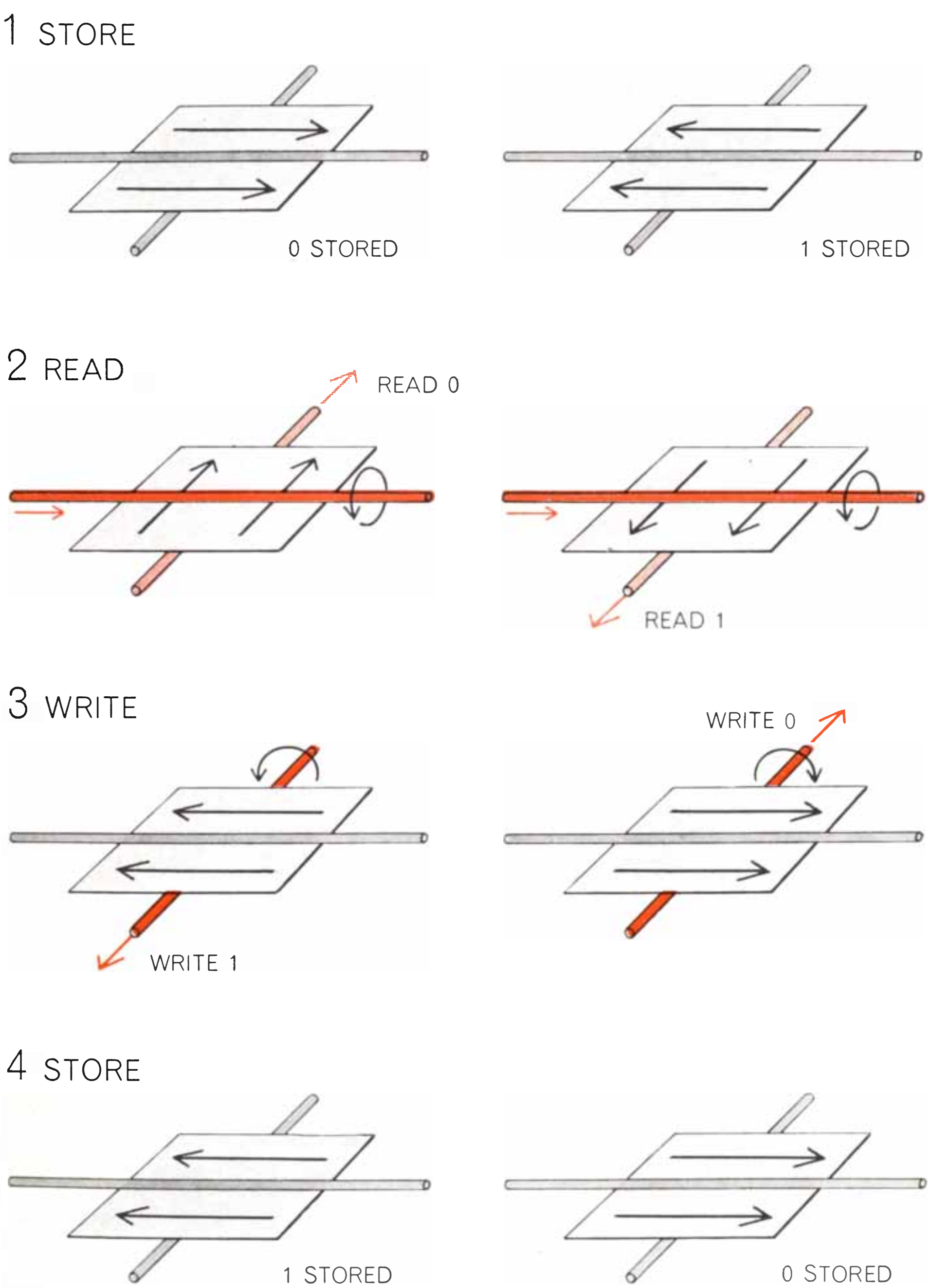
tive time was nearly prohibitive. Second, power consumed by vacuum tubes was so large that adequate cooling was extremely difficult to achieve. Third, the components were so large that the distances over which signals had to travel would have limited computer speeds to levels that today would be regarded as slow.

In 1948 the point-contact transistor was invented. It was small and used little power, but it was too unstable a device to replace the vacuum tube in large-scale computers. A few years later the junction transistor was developed, but it was too slow. In 1957 the planar silicon transistor was invented. It provided high-speed transistors that were reliable and made possible the design of the present high-speed computers. Further development of the planar technology led to the monolithic integrated circuit, in which scores of components are created and linked together in a single tiny "chip" of silicon. A variation of this technique is used to create the integrated-circuit memories.

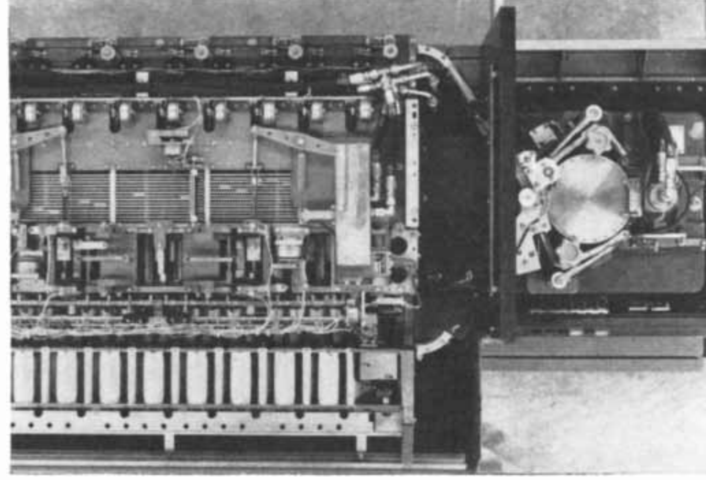
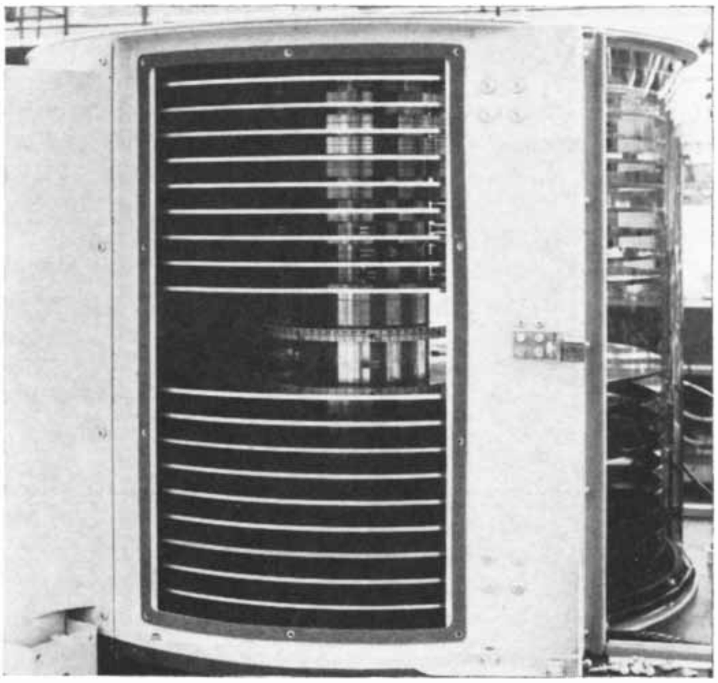
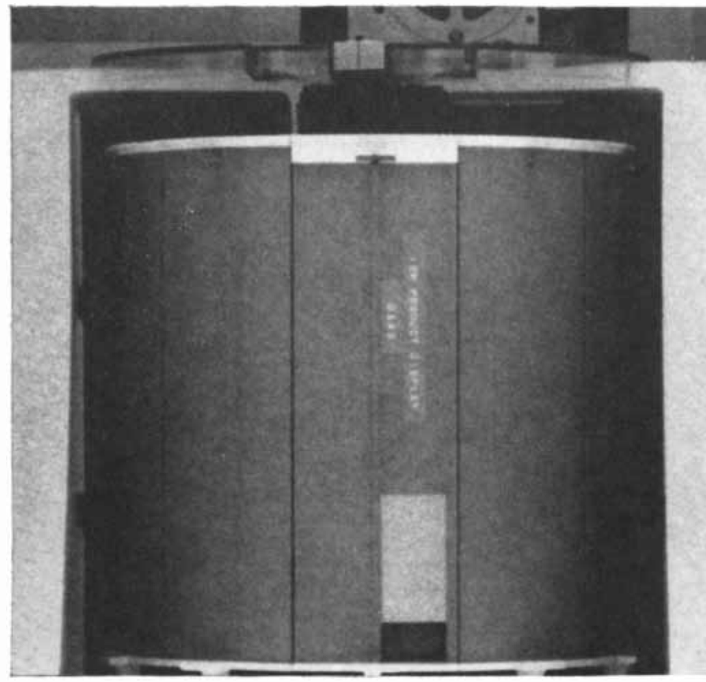
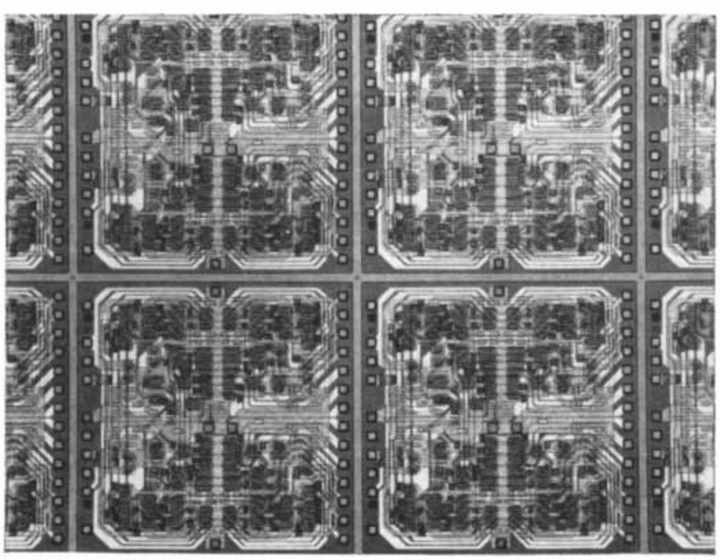
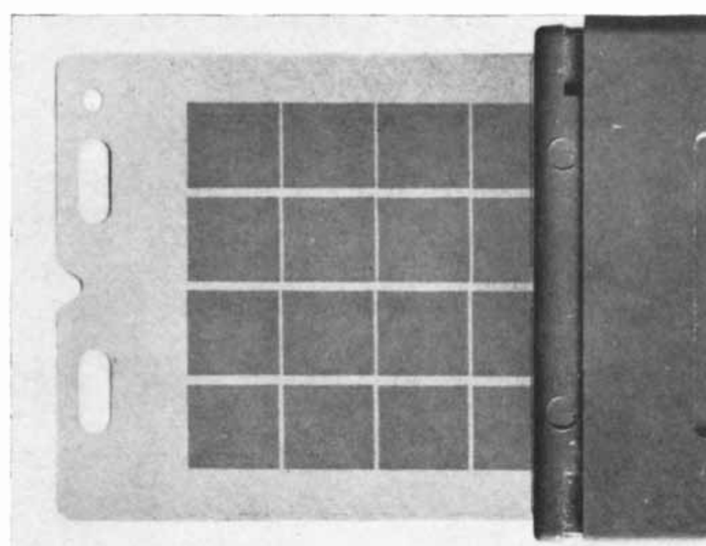
The integrated logic circuit, which is just beginning to make its way into large-scale use for computers, contributes substantially to the solution of the three problems that beset the vacuum-tube computer and that were only partially solved by discrete transistors. An integrated circuit on one chip of silicon can have the logic capacity of several of the logic circuits described earlier. It occupies far less space and consumes less power than an equivalent transistor circuit. Its small size makes possible systems with higher speeds because the interconnections of the circuits are shorter. Reliability is increased because the interconnections are themselves reliable. Indeed, the reliability of an entire integrated circuit is expected to approach that of an individual transistor. The latest integrated circuits have a signal delay of only a few nanoseconds, and still faster circuits are being developed. However, the physical size of a computer's components, together with their interconnections, remains a fundamental limitation on the complexity of the computer: an electrical signal can travel along a wire at the rate of only about eight inches per nanosecond (two-thirds the speed of light).

Computer technology has a way of confounding those who would predict its future. The thin-film memory, for example, has been "just around the corner" for more than 10 years, but the ferrite core is still the main element of random-access memories. Nevertheless, one can try to make certain predictions based on the situation at present. It now seems clear that integrated-circuit technology will soon produce circuits of great complexity at very low cost. These circuits will include high-speed memory circuits as well as logic circuits. Already one can get commercial delivery of a 100-bit register on a single chip of silicon that is a tenth of an inch in its largest dimension. It is my personal opinion that computer designers will be hard-pressed to develop concepts adequate to exploit the rapid advances in components.

Because computers built with integrated components promise to be much cheaper than present machines, one can expect significant changes in the comparative costs of information processing and information transmission. This in turn will influence the rate of growth of data-transmission facilities. Low-cost computers will also change the cost factors that help in deciding whether it is cheaper to do a job with human labor or to turn it over to a machine.



OPERATION OF THIN-FILM MEMORY differs from that of a magnetic-core memory, illustrated on the preceding page. One difference is that the read-out for a 0 or 1 is determined by the polarity of the voltage pulse in the sense wire rather than by the presence or absence of a voltage. Also, in the thin-film memory reading and writing are performed by passing current through different wires. Finally, the change in direction of magnetization that induces a read-out pulse involves a rotation of only 90 degrees rather than 180 degrees.

VARIETY OF MEMORY SYSTEMS are based on magnetism, electronic circuitry and photography. Magnetic-drum memory (*top left*), built by Univac Division of Sperry Rand Corporation, provides access in 17 milliseconds to any one of 786,432 36-bit words or some 4.7 million alphanumeric characters. "Random Access Computer Equipment" (*top right*), built by RCA, stores information on 2,048 flexible plastic cards. The basic unit holds 340 million alphanumeric characters; the average access time is 385 milliseconds. Magnetic-disk memory (*middle left*), made by Control Data Corporation, provides access in 34 to 110 milliseconds to any one of 131.9 million six-bit characters. "Data cell" system (*middle right*), offered by IBM, stores data on 2,000 narrow strips of magnetic film. It provides random access in 175 to 600 milliseconds to 800 million bits of information. Integrated-circuit memory (*bottom left*) provides access to 16 bits of information in about .01 microsecond. This example is made by Motorola Semiconductor Products Inc. A new photo-digital memory (*bottom right*) has been devised by IBM to provide rapid access to memory files containing a trillion bits. A single film chip, 1⅜ by 2¾ inches, can store several million bits of information; IBM is not yet ready to disclose the exact number.

COMPUTER INPUTS AND OUTPUTS

The input-output system of a computer consists of the programs and devices that allow the machine and its user to communicate. Recently graphical devices for this purpose have evolved rapidly

by Ivan E. Sutherland

If a computer is to be useful, it must obviously be able to communicate with the outside world. Data and programs have to be put into the machine before it can do any work. The computer must record and store for later reference information it has processed. Answers must come out of the computer in some usable form. The programs, mechanical devices and electronic circuits that perform these essential tasks of communication constitute what is called the input-output system of the computer.

A fact easily lost from view as a computer performs its prodigies of calculation is that a man is the reason for it all. He gives the computer data and programs and uses the results. Hence an input-output system has to cater to human needs as well as those of the computer. The total process from human recognition of a need that can be met by a computer to human use of the computer's answer consists of four parts. First, the data required must be put into a form the computer can use. Second, someone must tell the computer what to do. Third, the computer must read the data, process them and write the answers. Fourth, the computer's answers must be put into a form people can use. Input-output equipment must be designed to make each of these steps as easy as possible.

Improvements in input-output technique can lead to improved performance in all four parts of the computing process. For the input of data it is obvious that new kinds of input equipment make it possible for computers to accept directly a wider variety of information. A case in point is the recent development of stylus devices, such as the "Rand Tablet," that enable the computer to interpret human sketching. These devices make it possible to put diagrams and sketches into the computer without the time-consuming process of reducing them manually to numerical coordinates.

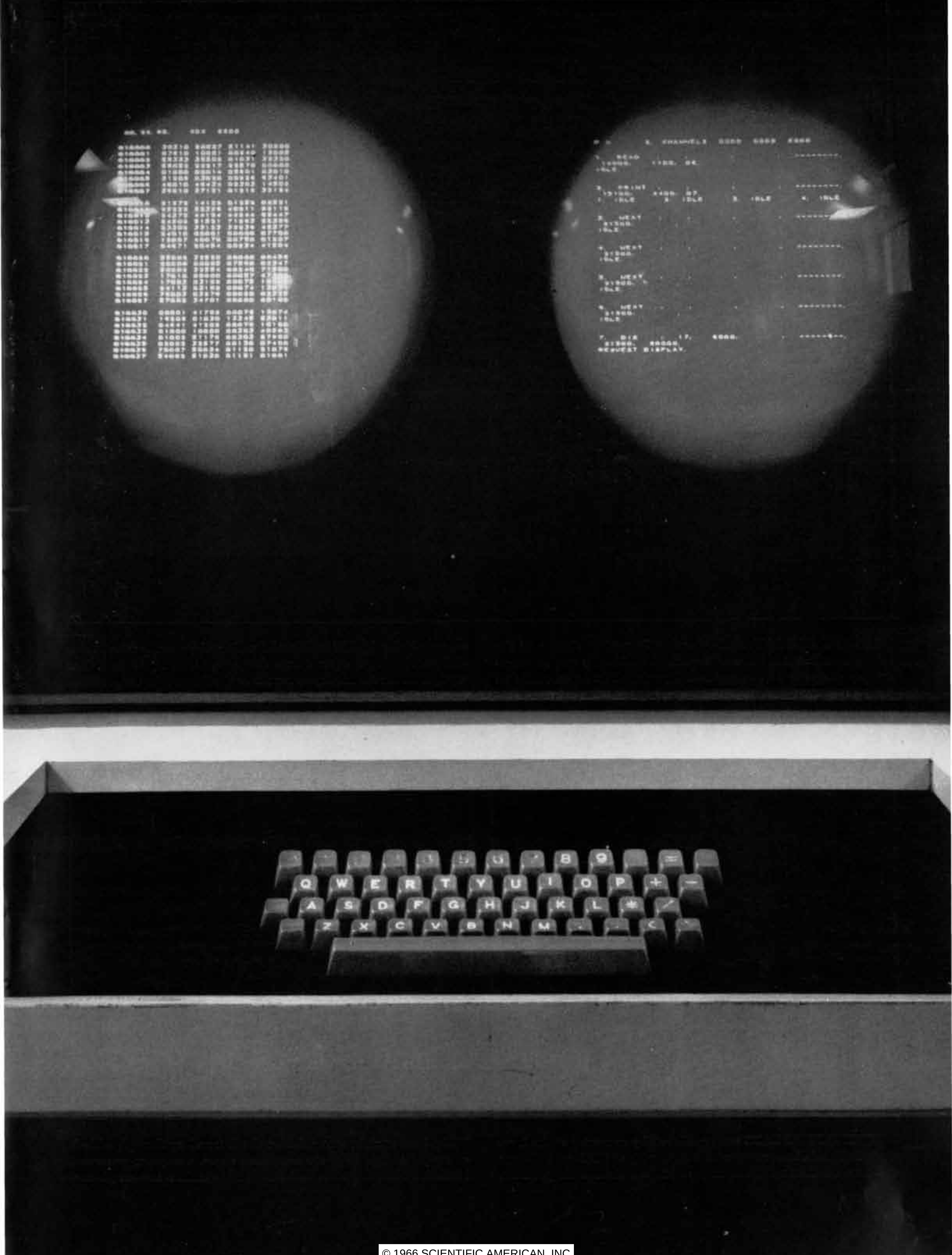
Secondly, and less obviously, the ability of the computer to accept a wider variety of input forms opens new ways of using such forms to specify what the computer is to do. For example, programming languages based on pictures rather than typed instructions may be much more convenient for specifying some processes of calculation to be carried out by the computer. Thirdly, improvements in the speed and organization of input-output systems can reduce computing costs. The "interrupt" systems I shall describe can reduce computing delays by allowing several input and output operations to proceed while computation is being done. Finally, new kinds of output equipment enable computers to produce output in more directly usable forms. A graph is often much more useful than a column of numbers.

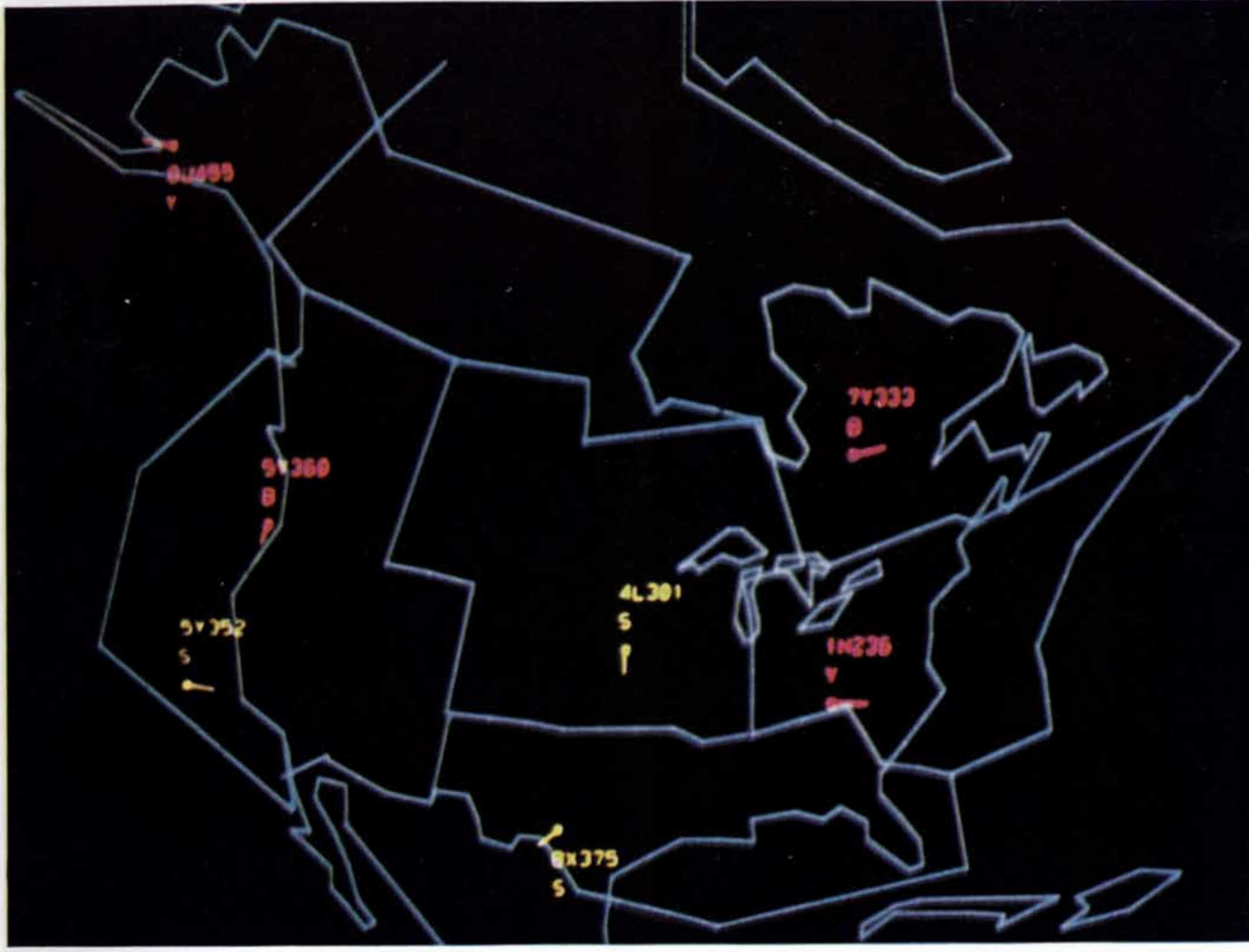
Until fairly recently nearly all input-output systems in general use were designed to economize on the computer's time at the expense of some inconvenience to the user. The reason was the costliness of delaying computation, which was considered to be the computer's prime function, just to get data in and out. As a result of many years of work we have learned how to make input-output equipment operate efficiently from the computer's point of view.

Although care is still taken to operate computers efficiently, much more attention is now being paid to human convenience. Recent developments such as time-sharing [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128] and reductions in the cost of computing, console and display devices have given us an unprecedented freedom in designing input-output equipment. New devices and programs, some of which will be discussed later in this article, are changing computers from hard-to-use consultants into ready tools to aid human thought. For the time being, however, these programs and devices are mainly experimental. First it would be well to consider input-output as it is generally practiced today.

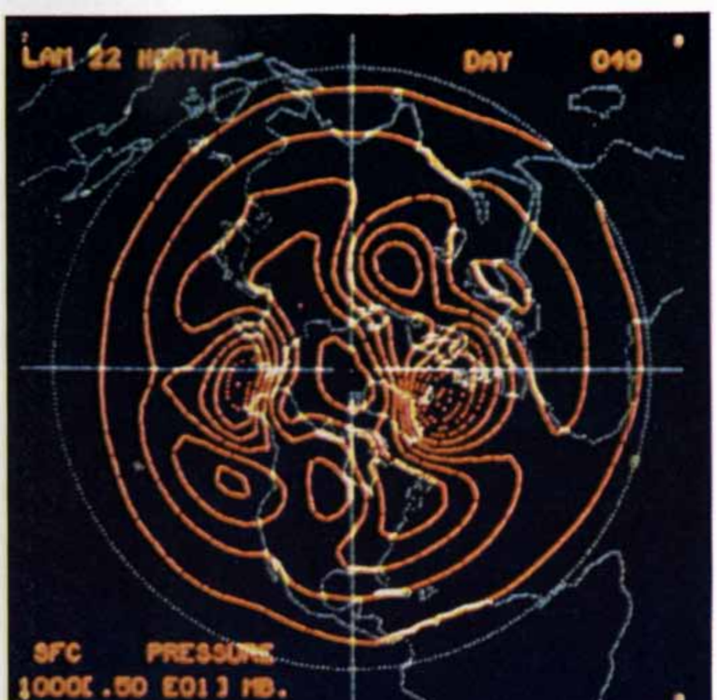
Different computer installations have quite different collections of input-output devices, even though the installations may have the same type of computer. The particular complement of input-output equipment depends on the purpose of the installation and is a strong factor in determining its price. A typical computer installation might have a card-reader, several magnetic-tape units, a typewriter and a high-speed printer. Information prepared on punched cards is entered into the computer through the card-reader. The magnetic-tape units provide the computer with storage for intermediate results. They can also provide for long-term storage of information and, by the transfer of tapes, for communication with other computers. The typewriter can be used for the output of short mes-

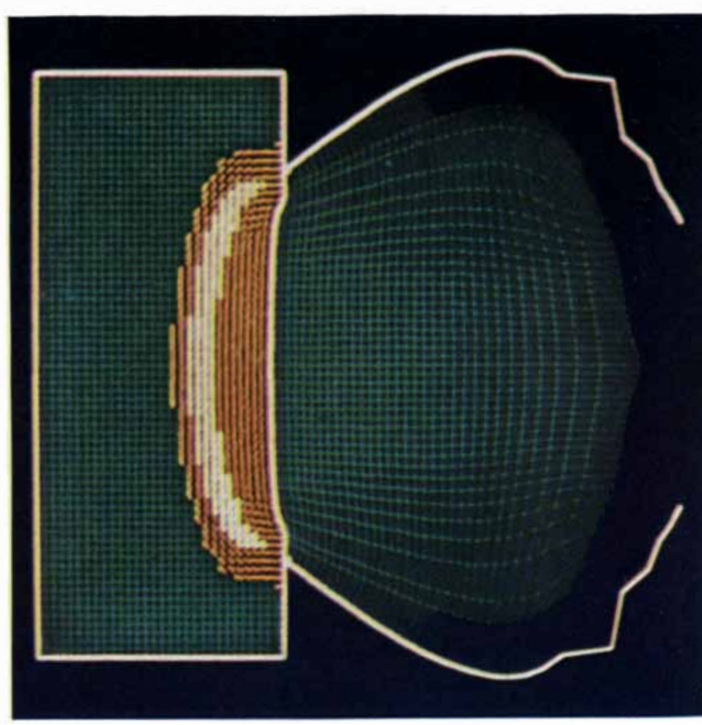
CONTROL CONSOLE of a computer representative of the most recent generation of computers is much simpler in appearance than the large panels of some earlier machines. This is the console of a Control Data Corporation 6600 computer at the Courant Institute of Mathematical Sciences at New York University. The keyboard is for input of instructions; the cathode ray tubes display (*left*) data from the computer's core memory and (*right*) the status of the seven problems the computer can handle at once.





MILITARY DISPLAY at the Combat Operations Center of the North American Air Defense Command (NORAD) can be generated by computer in 10 seconds and projected in seven colors on an area 16 feet by 12 feet. Here blue lines show continent and special subdivisions; other colors designate aircraft positions. The equipment for the display was made by the Burroughs Corporation.





SCIENTIFIC DISPLAYS were produced by computer at the Lawrence Radiation Laboratory of the University of California. Orange contours on meteorological map at left are surface air pressure. White lines at right are explosion shock traveling through a block of metal; orange lines are maximum stress. Computer generated black-and-white diagrams that were used to make a motion picture.

sages, such as one instructing the operator to mount a particular reel of tape. It can also be used by the operator to signal when computations should start, for instance when he has finished mounting the tape. The printer provides for the output of results.

The typical pattern of card-reader, magnetic tapes, typewriter and printer varies when there are special needs. Many installations have card-punches in addition to card-readers. Some low-cost computing systems use punched paper tape instead of cards, substituting tape-readers and tape-punches for card equipment. An array of magnetic disks, usually called a file, is sometimes used with or instead of magnetic tapes.

Switches and lights are often used at the console instead of a typewriter for control by the operator. Some computers drive more than one printer. Others operate entirely without printers, depending on auxiliary computers to print from magnetic-tape output produced by the master computer.

All the input-output devices connected to computers have been designed to run as fast as possible. They seem, when running, to consume or produce information at a prodigious rate. A fast card-reader reads about 1,000 cards per minute; it seems to speed through the pile of cards like a power saw cutting through wood. Similarly, printed pages come out of an output printer much faster than one can read them. Even a computer typewriter, one of the slowest of the input-output devices, types far faster and more accurately than a skilled human typist.

Nonetheless, the speed of such input-output devices is slow compared with that of a modern electronic computer. To see just how slow their operations are from the computer's point of view, let us imagine slowing down an entire computer system a millionfold. Instead of performing a million operations per second, our slowed-down computer will perform at a more human pace: one operation per second. In the slowed-down model a computer typewriter that normally types 10 characters per second would type about one character per day! To put it another way, a computer receiving input from a fast typist is much like a man getting one new character of a telegram each morning.

Most input-output devices are faster than typewriters, but because nearly all of them have mechanical parts they cannot approach the speed of the electronic computer. A computer printer that can print 1,500 lines per minute, each with 132 characters, would accept a new character every five minutes in our millionth-speed model. Magnetic tape that accepts about 100,000 characters per second would accept a new character every 10 seconds. Since it takes about two milliseconds to start or stop a tape in ordinary computer operation, however, it would take the tape unit in the slowed-down model half an hour to deliver its first character. On the other hand, some input-output devices (microsecond clocks, very-high-speed magnetic drums, cathode-ray-tube displays and converters that change data such as voltages into digits) can work as fast as electronic computers. Thus the difficulty of coordinating input-output processes with computing is not only that some input-output devices are extraordinarily slow compared with the speed of computers but also that the range of input-output speeds is very large.

Another difficulty is that the computer must be able to accept information from input devices and deliver information to output devices promptly on demand. Promptness is required because many input-output devices, once they are started, cannot be stopped quickly. For example, once a magnetic tape has started moving, new characters will come from it at regular intervals whether or not the computer accepts them. The inertia of the tape is too great to permit starting and stopping for each character. If the computer fails to accept a character before the next one arrives, information will be lost.

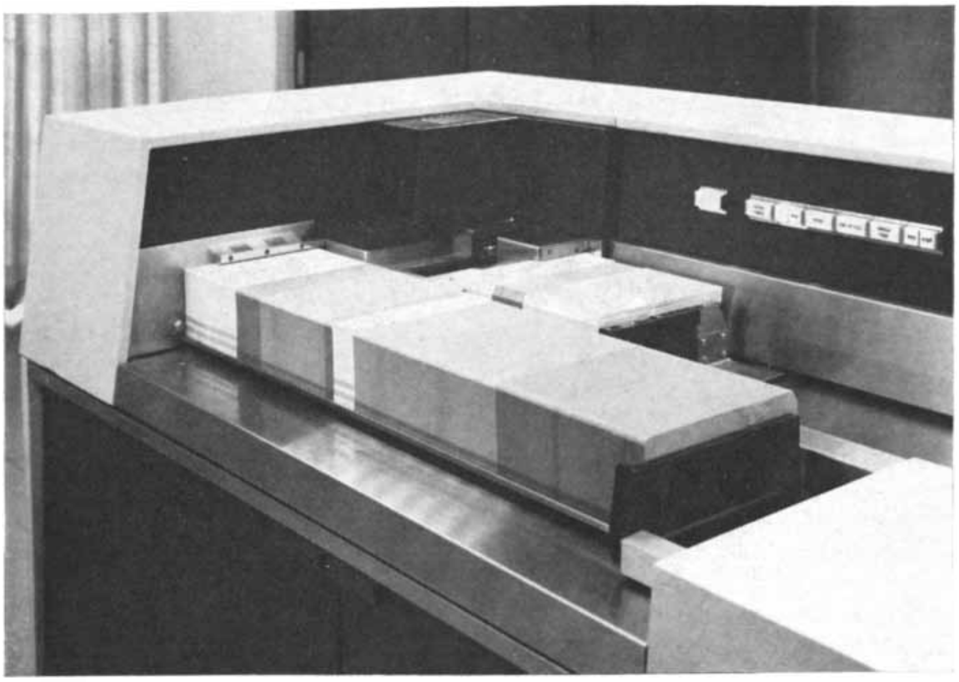
Although the computer must be able to handle each piece of information promptly, it can hardly afford to stand by idly. Modern computers are very costly, and each second they wait for input or output equipment to function corresponds to hundreds of thousands of irretrievably lost computations. Much of the complexity of modern computing systems arises from the desire of the designers to avoid unnecessary waiting for input and output. A well-designed modern computer can operate half a dozen or so input-output devices concurrently and do useful computation in the time left over. This is a juggling act of colossal proportions. Developing the computer hardware and programs to realize it has been a major task.

Most of the early computers lacked the hardware that makes efficient input and output feasible. A typical input-output system consisted of a few special instructions. They enabled a program to select and activate an input-output unit, transfer data to or from it and determine if it was ready for another transfer of data. With only these simple instructions it was easy to write a crude input-output program but nearly impossible to write an efficient one. The input-output programs in common use wasted the time between successive transfers of data in a "waiting loop," a set of instructions in which the computer asked repeatedly if the input-output unit was yet ready for another transfer of data. An efficient input-output program would have provided for useful computation in the time between data transfers.

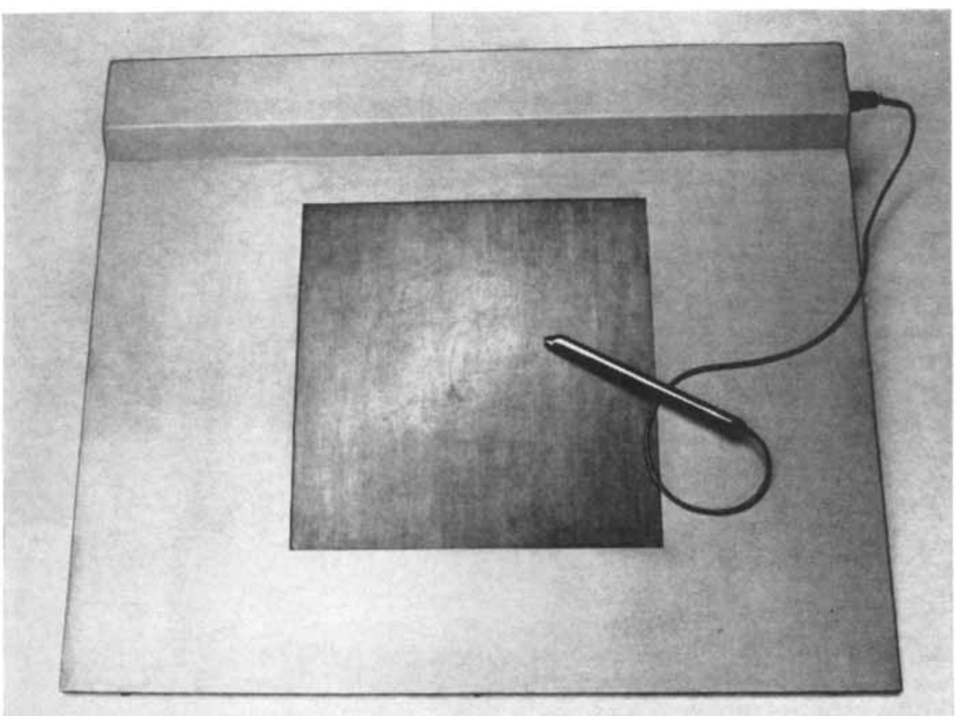
In the early computers computation between inputs or outputs of information could be done only if the instructions for input-output and those for computation were carefully interwoven. The programmer faced a dilemma. To obtain maximum efficiency he had to provide for as much computation as possible between transfers of data. If he allowed too much computation, however, input-output data would be lost. Writing an efficient program required a detailed knowledge of the timing of both the input-output operations and the computation. Since each new computation program presented its own special timing problems, every program required its own careful interweaving of input-output and computation. It was impossible to write, once and for all, an independent program to accomplish efficient input and output. The only independent input-output programs possible were the crude, time-wasting kind. Programmers either used inefficient input-output routines or faced the long, irksome task of interweaving input-output and computation.

The beauty of today's input-output systems is that they not only enhance efficiency but also provide for a clean separation of input-output programs from computation programs. It is this separation that enables programmers to use the full capacity of the modern computer.

The basic hardware required for efficient use of input-output equipment is the system of devices called the "program-interrupt." This hardware serves the computer as a kind of doorbell that signals the arrival of any important piece of information. When an input-output unit is ready to transfer data, it sends a signal to the interrupt hardware, which causes the computer to suspend whatever it was doing and execute instead a totally independent input-output program located somewhere else in its memory. The input-output



INPUT DEVICE in common use with computers is a card-reader, by means of which the computer "reads" data coded on cards with perforations. A typical card-reader, such as this one made by the Control Data Corporation, can handle about 1,000 cards a minute.



RAND TABLET represents a new generation of input devices that make the use of a computer easier by accepting the direct input of drawings. It has a sheet of Mylar etched with 1,024 copper lines on each side. Each line receives a unique series of electric pulses; they are coupled capacitatively through the stylus to tell the computer where the stylus is.

LIGHT PEN is another device that can put drawings into a computer. The pen contains a photocell that responds to spots of light displayed by a computer on a cathode ray tube. The pen has two uses: pointing at parts of a picture and (with a tracking program) drawing.

program transfers the data and then returns the computer to its former activity [*see top illustration on page 94*].

Program-interrupt hardware provides many advantages. Because it can interrupt a computation at any time, demands for input and output receive the prompt response they require. The input-output program runs efficiently because it is activated only when it is actually needed. Most important of all, efficient handling of input-output transfers no longer requires any complicated interweaving of computation and input-output instructions. Computation programs can now be written without regard for the input-output activities that may be under way simultaneously.

If several input-output units are connected to a computer, many interrupt signals can be generated at once. The priority to be given to these demands for service is usually designed into the interrupt hardware. Faster input-output equipment is generally given a higher priority. Units that operate at irregular intervals may get a lower priority if they can be made to wait; in this way they do not break the pace of synchronous units. Computation itself is given the lowest priority because it can nearly always wait. Computation takes place only when no interrupts are being processed, which usually turns out to be most of the time.

Most input-output interrupts result in the transfer of just one piece of information to or from the memory. Such an operation is described as one memory cycle. Often additional memory cycles are required to control the transfer. Some computers contain special hardware that processes each of the frequent but simple transfers of data in only one memory cycle. Such a unit, called a "data channel" or "memory-snatch" system, takes a single memory cycle away from calculation whenever an input-output device is ready [*see bottom illustration on page 94*]. A data channel or memory-snatch incorporates a pointer that is changed after each transfer, so that successive data are put into or taken from successive locations in the memory. It also contains a counter, so that only a specified number of transactions can take place automatically. Data channels are useful for very-high-speed tape and disk units that transfer new information every few memory cycles.

Although different types of computers use different kinds of interrupt systems, nearly every computer now being manufactured has some form of program-interrupt. Larger systems with fast input-output equipment usually include at least one data channel. Since it is uneconomical to interrupt the largest computing machines even momentarily for input-output, they are often directly coupled to a smaller computer that does their input and output for them. Since input-output operations rarely require sophisticated arithmetic, this separation of calculation and input-output is becoming more common.

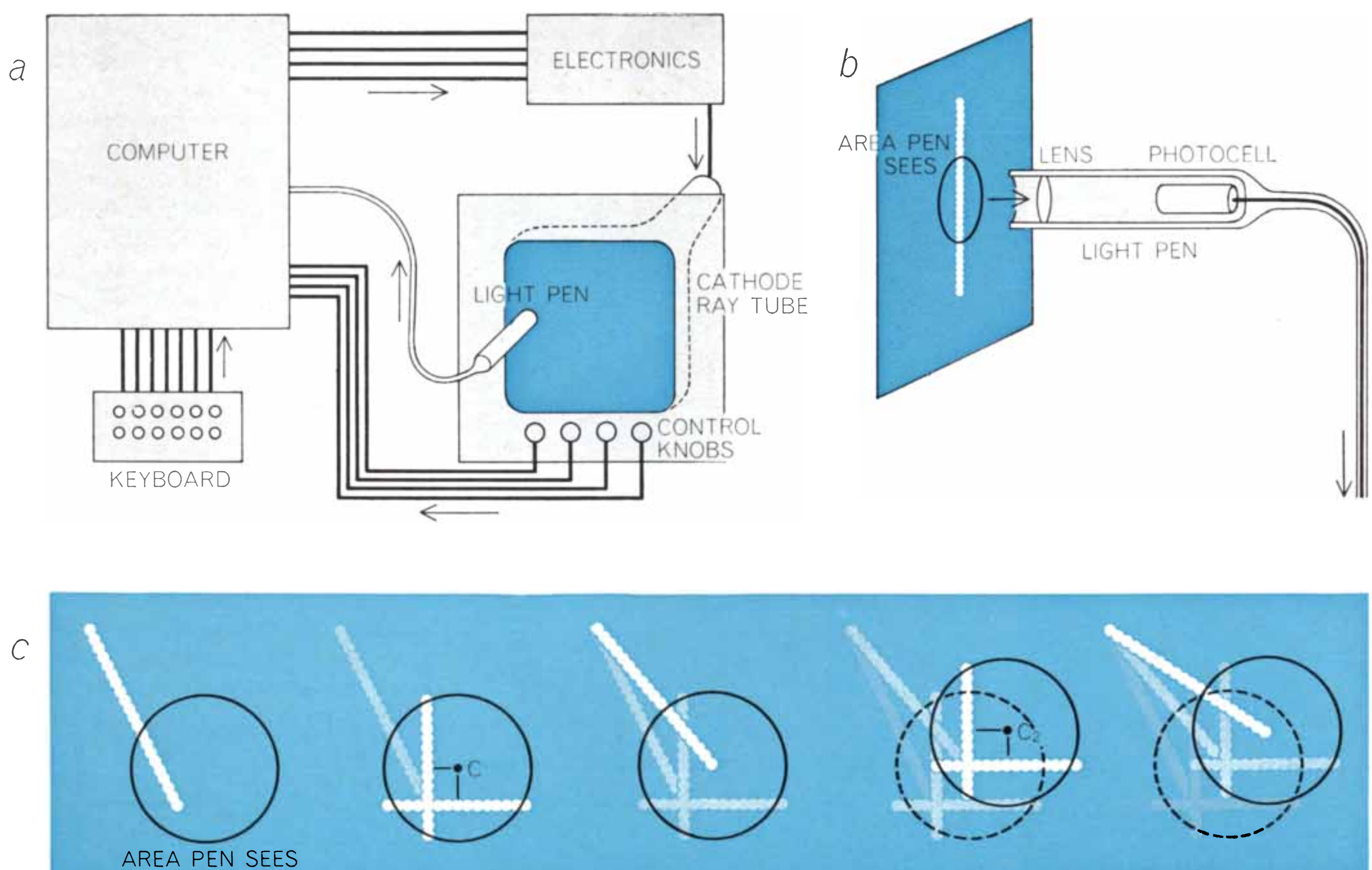
Most computers are delivered with a tape containing a comprehensive program (called an "operating system" or "executive") to do their input-output operations. The operating system should take care of all details of timing, running several input-output programs at the same time and dealing with correctable failure in the input-output equipment. Viewed through a well-designed operating system, input-output equipment is fast, accurate, economical of computer time and easy to use.

In addition to using the program-interrupt hardware to handle input-output operations efficiently, the operating system provides for the scheduling of jobs and the allocation of input-output and memory resources. Without an effective operating system a modern large computer is almost useless. In fact, operating systems are so important that they are usually covered in the specifications for a computer; failure of a manufacturer to deliver a suitable operating system on time usually results in a heavy financial penalty. The task of preparing a good operating system is substantial. Writing a new operating system is roughly equivalent in complexity to designing a new computer.

The operating system enables relatively unskilled programmers to utilize the parts of the computer they need without concern for details of timing, interference from other users or malfunctioning of equipment. For example, a user's program that requires the printing of data can call on a part of the operating system to perform the output. When asked to print, the operating system will accept responsibility for the data to be printed and will return control to the user program. If the printer is free, the operating system may begin to print the data at once. The user's computation program will proceed, interrupted from time to time when the printer actually requires transfers of data. If the printer is not free, the operating system may choose to put the data on magnetic tape for later printing. In this case too the user's computation will proceed, interrupted from time to time for data transfers. The operating system may check the information written on tape for accuracy. Should an error be found, the operating system will rewrite the information correctly.

All the complex activities of the operating system are accomplished by processing interrupts. The user for whom these processes are carried out has no need to be concerned with the details of the processing; indeed, he is quite unaware of them. Needless to say, the highly skilled system programmers who write operating systems must have an intimate knowledge of the input-output equipment and program-interrupt hardware involved.

Although the input-output programs and hardware described here solve the timing problems of using input-output equipment, they do little to assist in specifying the format of the



TWO USES of a light pen are pointing and drawing. Pointing ("*a*" and "*b*") tells a computer which parts of a drawing to erase or move. Drawing (*c*) is done with a tracking program. Here, to move the end of a line, the operator points at the end and pushes a "move" button; the computer follows the pen by displaying crosslike arrays of spots 100 times a second. Each time, the computer ascertains the outer vertical and horizontal spots seen by pen, computes position of pen's center and redisplays line to end there.

information transferred. The format in which information appears outside the computer is usually very different from that of the information inside. Humans want to see decimal numbers; computers normally use binary numbers. Humans want dollar signs, decimal points, separately printed units and separately printed exponents; computers just deal with numbers. Specifying the desired format for input-output information is an important part of any programming job. Converting information to and from the specified format is an essential function of the computer.

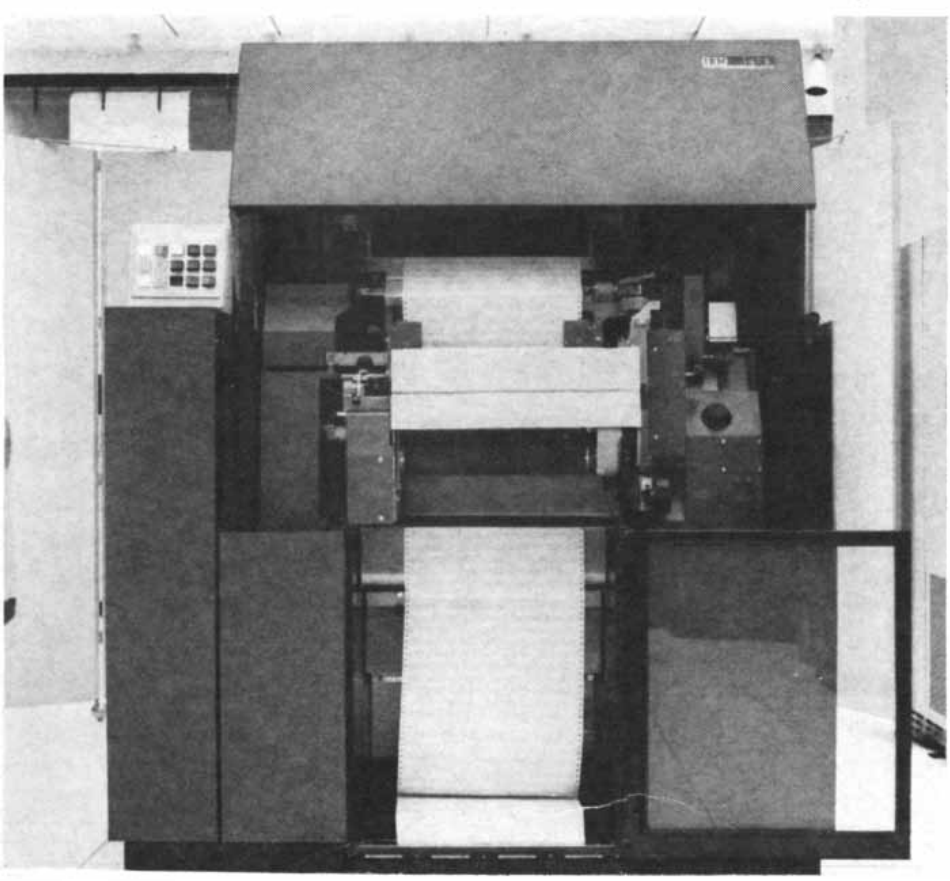
The specification and conversion of format are well understood for ordinary scientific and business computation. Formats consisting of columns of numbers with headings, convenient spacing and suitable units are easily specified through the "compilers" that most programmers use to help tell the computer what to do. Simple statements enable the programmer to describe each line he wants printed. For example, a format statement such as FORMAT (1H1, 4F10.3,5H FEET) would be interpreted by the computer as follows: 1H1, start a new page; 4F, print four numbers in decimal notation; 10.3, use 10 columns for each number and give three places after the decimal point; 5H, put the unit designation "feet" at the end of the line. Most compilers make it easy to print numbers as integers, as decimal fractions with a specified number of places before and after the decimal point or in scientific notation, such as 11.73×10^6 (which comes out 11.73 E6 in computers that cannot print superscript). In addition the computer can print comments, units and titles either from internal data or by copying part of the format statement.

Fairly simple formats serve for the large bulk of computer inputs and outputs. They are well matched to the limited capacity of the common output printers. Since most printers can print only capital letters, numbers and a few punctuation symbols, no great complexity of format is required. Most users of computers have become accustomed to receiving columns of numbers as the output from their computations. Research now under way, however, has shown that less common input-output devices and more complicated format-control tools for them can make much more useful forms of input and output possible.

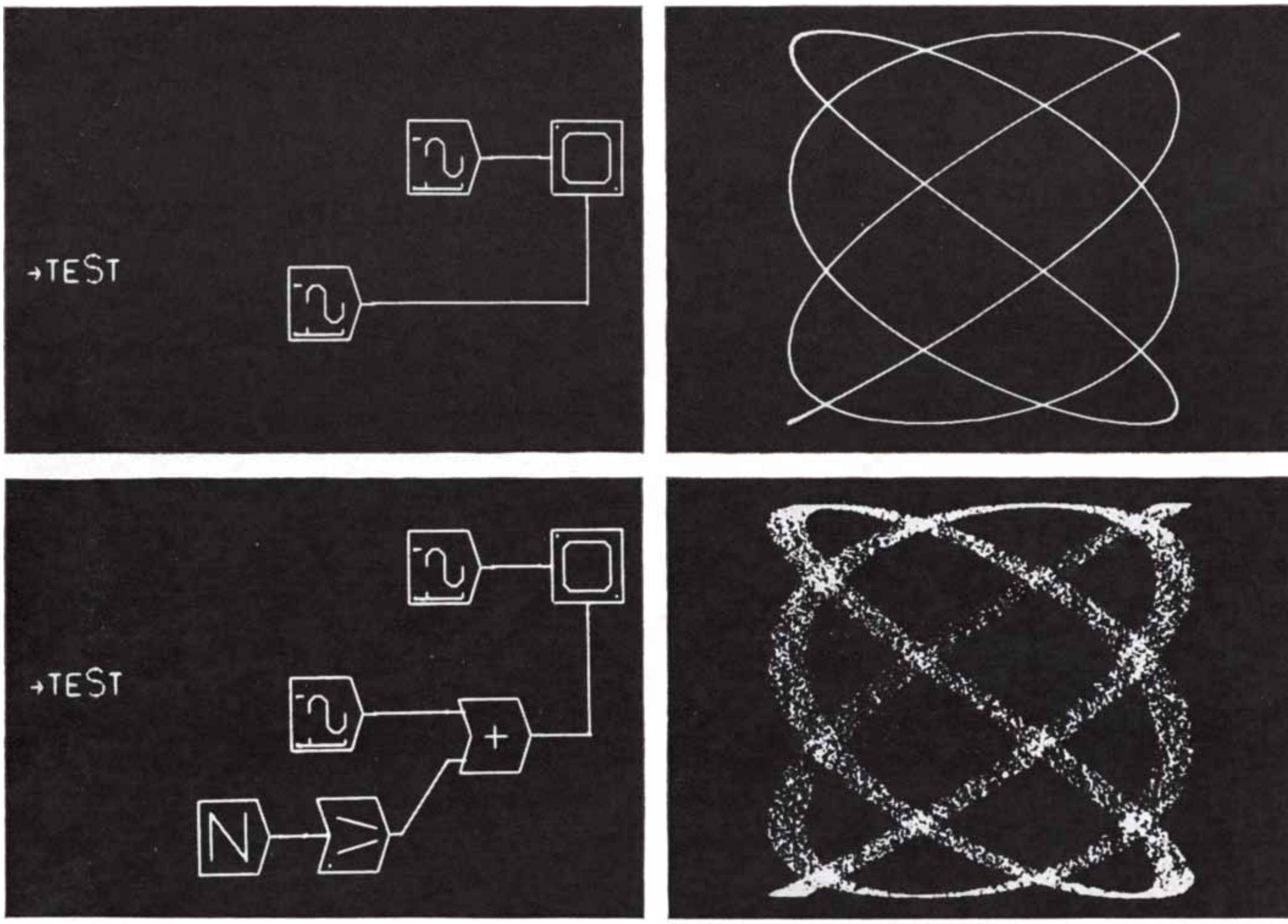
We are beginning to recognize that it is not enough for a computer to calculate and print an answer. The answer is useful only when it leads to new human understanding. Diagrams, drawings, graphs and sketches are essential tools for human understanding in many scientific and technical fields. All too often users of computers have been forced to convert pictures into numerical coordinates before giving them to a computer and to convert columns of numerical answers back into a picture or graph before understanding the answer. The time it takes a man to do the conversion keeps him from trying many examples; in some cases it may even cause him to lose sight of what it was he wanted. If the computer can accept information in the form most natural for the man and produce answers in the form he can most readily understand, it can be much more useful to him. The difference is readily apparent if one considers that a single straight line flashed on a display tube in one or two milliseconds might require 15 minutes of typed output to give the coordinates of the 1,000 or so points making up the line.

During the past few years several experimental systems have been built that rely on diagrams rather than printed or typed numbers as a medium of communication between a computer and its user. These systems have shown that proper use of graphical input-output equipment can produce a substantial increase in a computer's ability to aid human understanding of complex phenomena. In one such system, developed by Cyrus Levinthal at the Massachusetts Institute of Technology, protein molecules are shown in perspective [see "Molecular Model-building by Computer," by Cyrus Levinthal; SCIENTIFIC AMERICAN, June]. The effects of various assumptions on the shape of the molecule can be observed directly. In another system, devised by E. E. Zajac of the Bell Telephone Laboratories, the tumbling motion of a simulated satellite was recorded on motion-picture film. Engineers viewing the film were able to decide why the actual satellite's stabilizing system failed to work. Such demonstrations have hastened the development and application of computer systems that can accept and give graphical information.

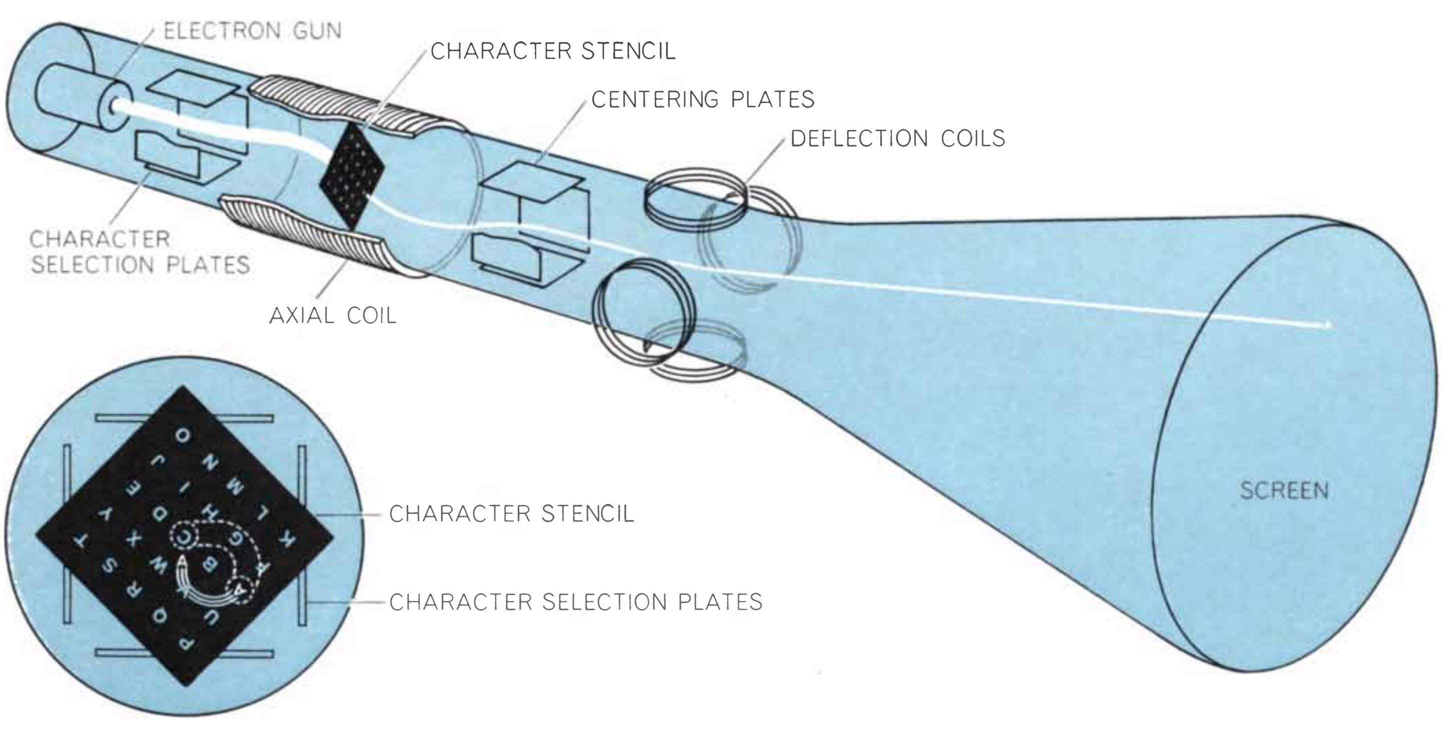
The basic hardware for graphical output is the cathode-ray-tube display, known around computer installations as the CRT display. Such a display contains a cathode ray tube and some electronic devices that enable a computer to control it. When given a set of coordinates by the computer program, a simple cathode-ray-tube display will flash the



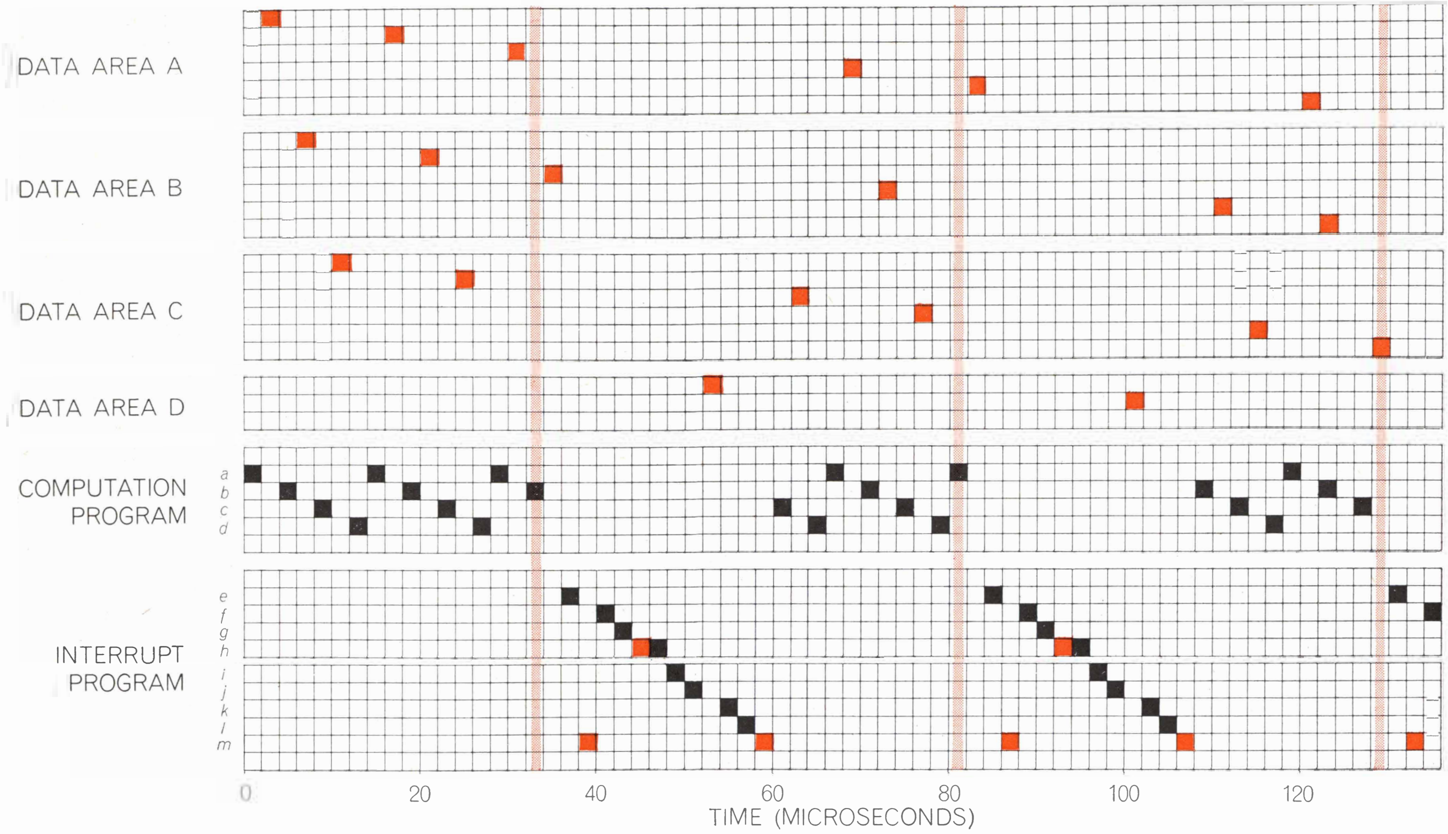
OUTPUT DEVICE in common use is a chain printer, which takes its name from the fact that the type is on a rapidly moving chain. This printer, which is made by the International Business Machines Corporation, produces 1,100 lines of 132 characters each per minute.



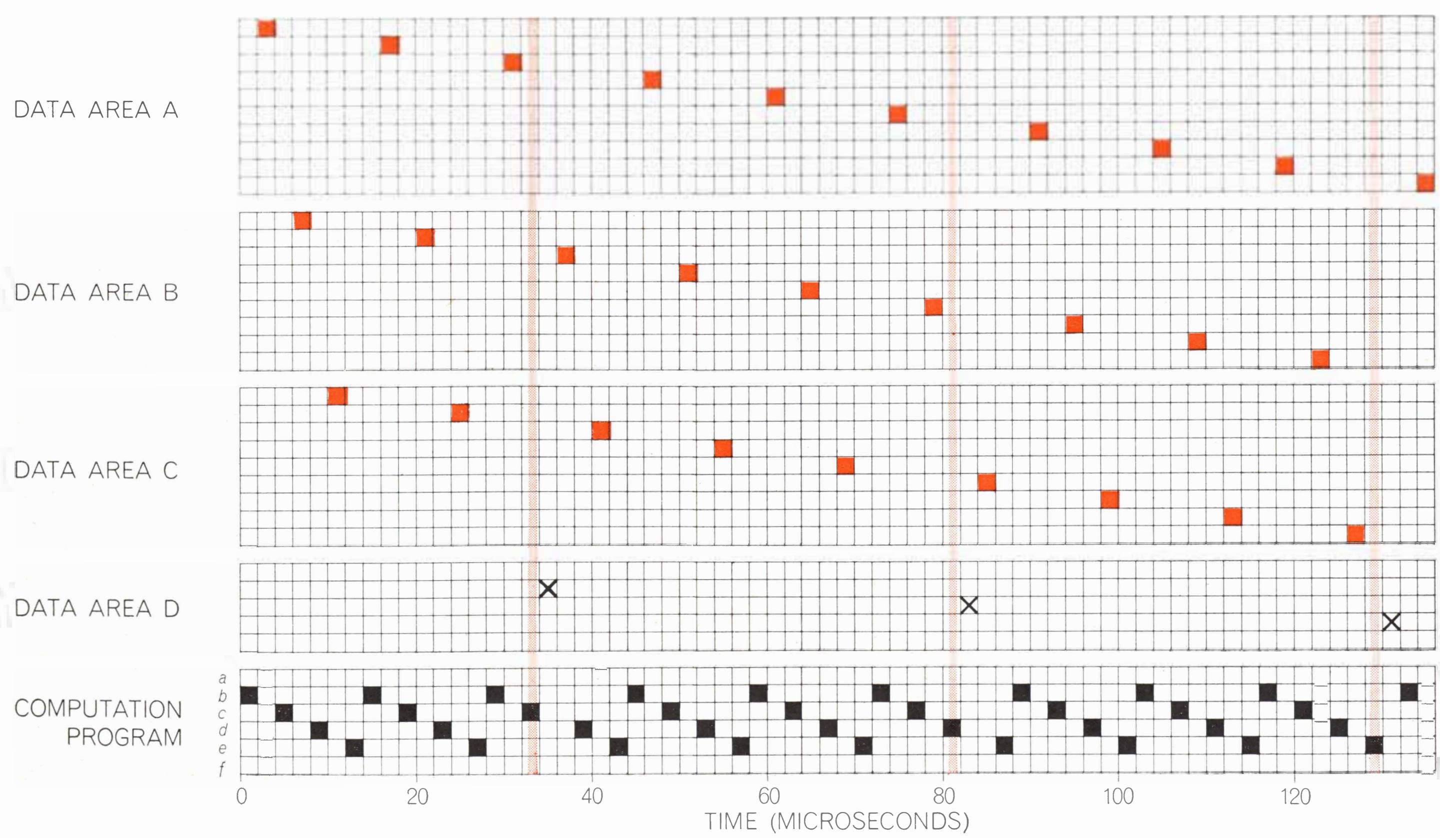
PICTURE INPUT AND OUTPUT on a computer, using a cathode-ray-tube display, are demonstrated with a program written by William R. Sutherland of the Massachusetts Institute of Technology's Lincoln Laboratory. At top left a light pen has been used to position predrawn circuits on the tube and to draw "wires" connecting them. Diagram instructs computer to simulate two sine-wave generators connected to an oscilloscope; the frequency and amplitude of the generators were specified on a typewriter. The resulting output is Lissajous figure at top right. At bottom the addition of a noise generator (*N*) and an attenuator (*slanting bars*) modifies output.



CATHODE RAY TUBE is equipped to print letters and symbols in a computer's output display. A broad beam of electrons emerging from the electron gun passes through electrostatic plates that deflect it toward the desired part of a stencil bearing the characters. In this case the beam is directed through the letter *A;* it is recentered in the tube by the centering plates and then deflected to the desired place on the display tube by the deflection coils. During passage through the tube the beam makes a three-quarter helical turn.



PROGRAM-INTERRUPT SYSTEM stops a computation while a computer deals with the input or output of data. Each square represents a memory cell of the computer; when such a cell is used to instruct the computer it is black, and when a cell is used for the storage or retrieval of data it is in color. In this program the computer is adding pairs of numbers and storing the sums. Periodically (*colored bands*) the computation program receives a signal from an input or output device; computation is then interrupted while the computer goes through the steps (*e–m*) required to deal with the input or output of data. Thereafter the computing is resumed.



"MEMORY-SNATCH" is similar to a program-interrupt except that each input or output of data takes only one memory cycle (*X*) and so computing is interrupted for shorter periods. In the program-interrupt system control of the computer passes to the interrupt program during the input or output transaction; in the memory-snatch, whenever an input or output unit is ready to transfer data, the single memory cycle immediately after the input-output unit's signal is used to put the datum directly into the computer's memory (*area D*) and computing then proceeds. The computing in these examples has been made simple for illustrative purposes.

corresponding spot on its face. Complete pictures including lines, curves and letters can be made up out of thousands of individual spots. Because the display is entirely electronic, it can work very fast; a single spot may take only a few microseconds to show.

This process has its limitations. The more elaborate the picture, the longer it takes the computer to compute the coordinates of all the thousands of spots in the picture. For this reason some displays have circuits that can paint straight lines on the display face automatically, thus eliminating the need for a program to compute coordinates for all the spots on each line. Since computer output usually contains some letters and numbers, many displays contain character-generating hardware that will cause a letter or number to appear on the display screen automatically. The character is formed either by passing the cathode ray through a letter-shaped mask or by electronically manipulating the beam to paint the letter [*see bottom illustration on page 93*]. Display hardware for generating various conic sections automatically is now being developed.

Making good use of cathode-ray-tube display equipment often requires quite complex programs. The few installations that now make extensive use of such displays have built up libraries of programs for producing a variety of display formats. Programs for producing bar graphs, contour plots, scatter diagrams and a wide variety of other useful formats are separately available. If the format desired does not fit one of the available forms, careful individual programming of the new format is required. It is fairly easy to program simple formats such as graphs, but it is considerably more difficult to get all the labels, scales and notes in the right places.

Some output formats are quite difficult to achieve. An adequate view of a solid object, for example, must have hidden lines removed [*see illustration on next page*]. It is easy to write a program that can compute the apparent position of each part of an object from the shape of the object and the desired viewing angle. It is very much harder to write a program that can decide which parts to omit to make the object look solid; moreover, the task of elimination takes much more time than the simple transformation of coordinates. Similarly, it is difficult to program a computer to place the parts of a drawing wisely so that its topology will be clear. For these reasons output plots of family trees, simplified circuit diagrams, organization interaction diagrams and the like are rare.

With suitable attachments a cathode-ray-tube display can also be used as an input device. Since the parts of a picture displayed on a cathode ray tube are "painted" on the tube face one after another, a photocell placed where light from a part of the tube can fall on it will respond when it detects light. The computer can tell what the photocell saw by noting when it responded.

In one arrangement the photocell and cathode ray tube are used as a scanner: the photocell is placed behind an exposed film on which is recorded some data such as the tracks of nuclear particles. The computer can then read the data from the film by noting which displayed points are hidden from the photocell by opaque parts of the intervening film. Scanners of this type are now manufactured commercially for converting data from photographic to digital form, so that the computer can make the desired calculations. These scanners are proving to be a boon to physicists who need to scan hundreds of thousands of frames from a bubble chamber to find a single significant event.

Picture input through scanners requires more complicated programs than picture output. Although a cathode-ray-tube scanner can tell a computer which parts of a photograph are opaque, a complicated program and a good deal of computer time are necessary to convert that information into a simple usable fact. Lawrence G. Roberts of the Lincoln Laboratory of M.I.T. wrote such a program for recognizing solid objects from photographs. Roberts' program demonstrated its ability to recognize simple plane-faced objects by drawing additional views of them. Although the computer required only a few seconds to read prerecorded picture data from tape, it took several minutes (an enormous amount of computing time) for the computer to make sense of the data. Pattern-recognition programs such as Roberts' and those used in analyzing the tracks of nuclear particles must be written on an individual basis. Because of this exacting requirement picture-scanning input is economical only experimentally or where there are large bodies of data to process.

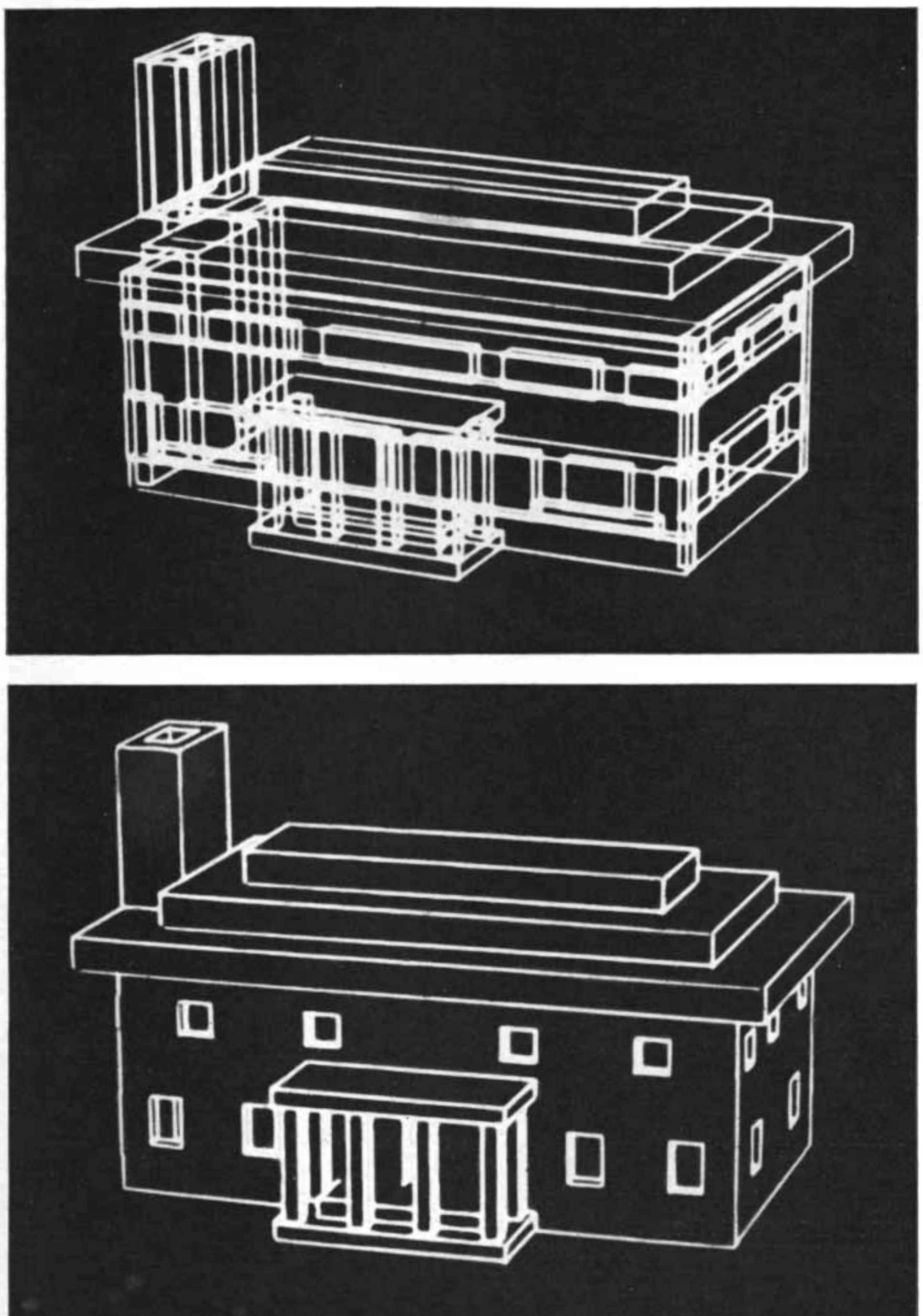
The stylus-photocell arrangement called the light pen can be used to make the cathode-ray-tube display serve for the manual input of sketches and diagrams [*see illustration on page 91*]. For this purpose the photocell is placed in a small hand-held tube. Since the photocell responds only when light from some part of the cathode-ray-tube drawing falls within its limited field of view, it can tell the computer which part of a drawing its user is pointing at. With an appropriate feedback program a light pen can also be used to enter position information into the computer. Other stylus input devices that detect the position of the stylus through electric and magnetic-field effects can serve a similar function. Some of these, such as the Rand Tablet (developed by Thomas O. Ellis of the Rand Corporation), provide the computer not only with position but also with a "pencil down" indication; that is, the device signifies to the computer not only the position of the stylus but also whether or not the user is pressing it down. The "pressing down" signal can be used to signify lines that are to be retained in the computer.

In a drawing system based on input from a stylus the computer interprets motions of the stylus and instructions given by the operator through push buttons or a typewriter keyboard; from these data the computer constructs a drawing in its memory. The program displays the growing drawing on a cathode-ray-tube display [*see top illustration on page 93*]. Unlike an ordinary pencil, the stylus itself does not make any direct mark on the display. The computer is placed, in effect, between the "point of the pencil" and the "paper." Because the drawing is built directly in the computer's memory, no complicated pattern-recognition programs are required. A stylus-input device therefore provides a convenient method for getting diagrams, circuits, geometric shapes, chemical symbols and other pictorial data into a computer.

Such a drawing system is very different from ordinary drawing with pencil and paper. Because the computer is placed between the "point of the pencil" and the "paper" it can assist in every step of drawing. For example, the computer can display lines as straight even though they were sketched badly. It can join lines at mathematically precise corners in spite of slight human errors. It will erase without any trace, or temporarily if you prefer, any unwanted line you point to. It can quickly copy any part of the drawing. It can stretch parts of the drawing to make them fit with other parts. It can move lines you have already drawn. It can refuse to draw lines that are meaningless in the context of the work in hand.

Most computer drawing systems use

push buttons as input devices to signal what action is desired. An experimental system at the Rand Corporation, however, uses motions of a stylus as the exclusive control. Since the Rand program is intended for drawing block diagrams, it recognizes crudely sketched blocks and substitutes neat ones for them. It also recognizes lines drawn between boxes as logical connections between them. No matter how you draw the connection, it will appear as a series of straight-line segments. It will have an arrowhead at one end. The Rand program also recognizes printed characters. It substitutes its own highly precise printing for your letters. It is impossible to leave bad printing on your drawing. You can insert letters by making a caret, whereupon the program will push existing letters aside to make room for your addition. You can erase boxes, lines and letters by making a score-out mark over them. With these facilities you can quickly and easily sketch out or modify a diagram.



PERSPECTIVE VIEWS of solid objects can be displayed by a computer. It is easy to prepare a program that will cause the computer to display every part of an object (*top*). It is much more difficult to write a program that will achieve the effect shown at bottom by causing the computer to remove certain lines from the display. Even with an appropriate program it takes the computer a relatively long time to carry out the instructions. The program for this display was written by Lawrence G. Roberts of the Lincoln Laboratory.

The topology of a drawing sketched into a computer with a stylus-input device is available explicitly in the computer's memory. If the drawing represents a circuit, for example, the electrical connections shown in the drawing will be represented in the memory in a form suitable for use in a circuit-simulator. The computer will "know" that two terminals are connected because it will have "watched" while the connecting wire was drawn. There are many computer applications for which specification of topology is important. Stylus input is beginning to be used to state topology for circuit simulation, analysis of communication networks, digital simulation of analogue systems and diagramming the flow of digital-computer programs.

The geometry of shapes is also stated easily with a stylus-input device. The stylus serves to sketch the part. If exact dimensions are important, they can be entered through a keyboard. In one case the parts specified by this technique are cut out by computer-controlled machine tools. In another case the computer does engineering computations on the shapes as an aid to the design of mechanical devices.

Stylus input to computers opens up new vistas for the application of computers. We are just beginning to explore these vistas. The ability to specify topology, for example, will make possible a new generation of computer-programming languages based on pictures rather than on written words. The ability to specify geometry will bring computers into use as aids to mechanical design. The ability to specify graphical-output formats will make possible ever clearer presentations of computed results. Perfection of the techniques for drawing with a stylus will make a stylus and computer easier to use than pencil and paper.

Although the full potential of graphical input and output is still unknown, there is a growing belief that important new insights will be gained through its use. Today graphical capability is unknown at most computer installations, even major scientific ones. Widespread recognition of its potential, however, is a strong motivating force that will bring graphics to the computers in most scientific research programs. It is my conviction that the widespread use of graphical inputs and outputs with computers will bring about a major increase in scientific, engineering and educational productivity.

It's a good system if you like it

> **There are slots.**
> **Slots need people to fill them.**
> **Someone exists who was born and educated to fill each slot.**
> **Find him. Drop him in. Tell him how lucky he is. Look in once in a while to make sure he still fits his slot.**

This orderly concept has much to commend it, plus one fault: some of the people most worth finding don't like it. Some very fine employers have not yet discovered the fault. It is not up to us to point it out to them. Luckily for us, we needn't be so tightly bound to the slot system.

We can offer *choice.* A certain combination of the factors diversification, size, centralization, and corporate philosophy makes it feasible to offer so much choice.

Choice at the outset. Choice later on. Choice between quiet persistence and the bold risks of the insistent innovator. Choice between theory and practice. Choice between work in the North and South. Choice between work wanted by the government and work wanted directly by families, by business, by education, by medicine, by science. To the extent that the slot idea helps channel choice we use it, of course.

A corporation such as this is one means of coordinating the strength of large numbers of effective persons. You may feel that in the years ahead this type of organization must change. You may feel that it must not change. Either way, to get a chance to steer you have to come on board.

Advice to electrical engineers, mechanical engineers, chemical engineers, chemists, and physicists—still on campus or as much as ten years past the academic procession: while one starts by filling a slot, it soon proves more fun to make one. No detailed list of openings appended herewith. Next week it would be different. *G. C. Durkin is Director of Business and Technical Personnel, Eastman Kodak Company, Rochester, N. Y. 14650.*

What's an isomer, Jim?

2′,7′-Bis(acetoxymercuri)fluorescein (EASTMAN 9963), or fluorescein mercuric acetate (FMA), as it is called by the sensible people who discovered that its fluorescence is quenched by a thiol group or at high pH by a disulfide group, has become the reagent for detecting 10^{-10} mole of disulfide by spraying an alkaline solution on a paper chromatogram. Their publication (*Anal. Biochem.*, 9:100 (1964)) slightly predated the advent of the EASTMAN® CHROMAGRAM® System of thin-layer chromatography, which may well turn out to yield faster and better resolved separations for this visualization technique. They also describe a procedure with a solution of the reagent for the continuous assay of cystine-containing peptides in column effluents. Interest runs high in such peptides. Disulfide links are important in giving proteins their immunologically significant shapes.

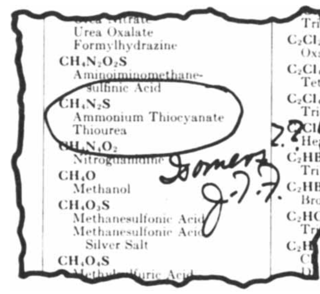
EASTMAN *9963 is one of 1173 new items by which the brand new List No. 44 of* EASTMAN *Organic Chemicals is richer than its predecessor. A copy of List No. 44 is obtainable free from Eastman Organic Chemicals Department, Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company).*

A grandfather named Jim Fuess runs the department. One measure of what he has accomplished by investing much of his life in his job is the number of authors in the world's chemical literature each year who see fit to mention Eastman as their source of compounds, despite having paid full catalog price for them.

For List No. 44 Jim decided on a new attack against the nomenclature problem that so often frustrates buyers and sellers of organic compounds as they seek each other. The approach is characteristic of the guy: uncomplicated, unpretentious, and if nobody is dazzled by the brilliant originality of the concept, so much the better.

Let us, said Jim, triple the number of "see" references in the alphabetical listing and follow the alphabetical listing with a complete list of empirical formulas arranged according to numbers of atoms of each element in the molecule. Where several names fall under the same empirical formula, customers ought to know enough chemistry to pick the right name.

And that's what you'll find in List No. 44. As it happens, intramural busybodies occasionally intrude into Jim's communications with his customers. One such, an advertising copywriter by trade, has slipped into the catalog a statement about how the empirical list "offers the old concept of isomerism as the bridge from a structural formula to a choice among EASTMAN Organic Chemicals of the same empirical formula." Old dictionaries notwithstanding, Jim doubts that his friends regard ammonium thiocyanate and thiourea as isomers.



Moving movie film from camera to projector

When you make motion pictures for scientific purposes, you have to do something about getting the film processed. For slowing down action, speeding it up, or recording it as it was, movies are too valuable to be foregone because of processing complications. The issue can be ducked with grace.

If your organization makes enough movies to maintain its own captive processing facilities, the complications get turned over to people who are paid to take them all in stride. This is a very convenient arrangement that can even put the organization into the silver-mining business as an additional source of spending money.*

Outside your walls there are reliable companies that make a living at processing movie film. The channel that supplies your raw film may be able to put you in touch with them.

The company that made your KODAK EKTACHROME MS, ER, or EF Film can also process it for you. You pay for the service by purchasing a KODAK Prepaid Processing Mailer PK10 from a Kodak dealer and mailing 100 feet of film in it to the nearest Kodak Processing Laboratory on a list printed in the mailer. This is about as uncomplicated as you can get.

If that is a little too simple for your taste or needs, you can ask for more speed.

You can mean that two ways, and we are ready to deliver on either or both of them. You could mean you want the exposure index effectively doubled in the processing, a neat trick for which these particular films were designed. Dealers can quote on this special Kodak Processing Service, just as they handle Kodak processing for lengths exceeding 100 feet. "Speed" could also mean that you want us to make a special effort to have the processed film back in the mail to you within 24 hours of receipt at our nearest processing lab. This Commercial Expedited Processing Service carries a small extra charge which the dealer can quote, but it is of limited availability and may be a waste of small change. We say that because a vast amount of Kodak-processed film gets mailed back within 24 hours anyway, without additional charge.

If you need the name of such a dealer or any other processing information about EKTACHROME *Films for technical motion pictures, ask Instrumentation Products, Eastman Kodak Company, Rochester, N.Y. 14650.*

*Some Kodak dealers offer an arrangement whereby they credit your account for silver from spent processing solutions, recovered by the simple means of a KODAK Chemical Recovery Cartridge. Thus a rare natural resource is conserved for reuse, not dispersed into the environment.

The hope of doing each other some good prompts these advertisements

Kodak

Mail letters over the phone!

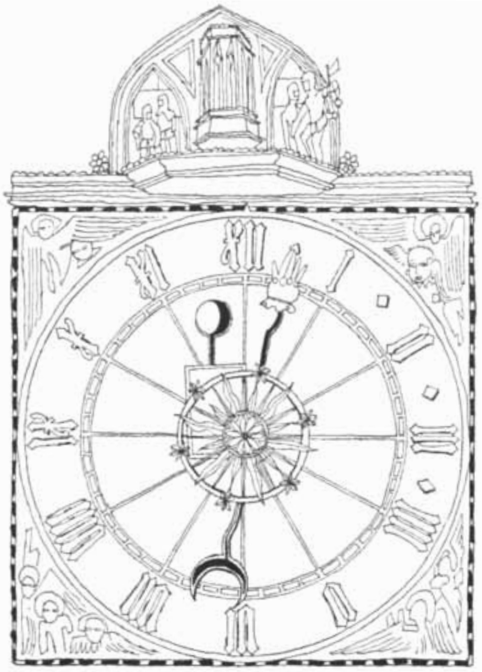
The amazing Xerox Magnavox Telecopier can send an exact copy anywhere in the country. Over ordinary telephone equipment.

2. Pick up your telephone and dial a number. Any number anywhere in the country.
3. Lay the receiver on the coupler.
4. Minutes later an exact copy of your letter comes out of the Telecopier at the other end of the line. The amazing Telecopier sends and receives exact copies of anything written, printed, drawn, typed or photographed. Any distance. Over ordinary telephone equipment.

Think how many ways you could use a Telecopier. When you get to a million, call your Xerox Copy Analyst.

The Xerox Magnavox Telecopier

XEROX



Medicare and Medicaid

For approximately 10 percent of the U.S. population the economic risk of hospitalization for injury or acute illness is now covered by compulsory social insurance. The coverage extends to virtually all the 19 million persons in the U.S. who are 65 or older. They are the principal immediate beneficiaries of the amendments to the Social Security Act adopted by Congress in 1965. Under Title XVIII (the much debated "medicare" chapter of this legislation) these people also become eligible for tax-subsidized voluntary insurance against doctors' bills. By July 1 of this year, when the legislation took effect, more than 17 million of them had signed up for this protection as well.

For the overwhelming majority of its clientele medicare makes it possible to seek as solvent consumers the medical services they would otherwise receive as objects of charity or public assistance or might not receive at all. The compulsory, or "automatic," hospital insurance, now extended as an added benefit from social security premiums, provides for all but $40 of the costs of hospital service (semiprivate) for the first 60 days and all but $10 per day for an additional 30 days in each period of illness. "Posthospital" services, taking account of the chronic nature of the ills of the elderly, are also made available. These include physical, occupational and speech therapy, home nursing and (after January 1, 1967) coverage of all but $5 per day of a 20-day stay in a convalescent home. The voluntary insurance against doctors' bills pays 80 percent of "reasonable charges" by physicians and surgeons. In addition to the premium payments of $3 per month, which are matched by the Federal Government, the beneficiary must pay the first $50 of doctors' bills each year.

Medicare and the other actuarial benefits provided in the 1965 legislation will raise social security outlays from about $19 billion to $25 billion in 1967 and to still higher levels in the future. To finance these outlays Congress increased the income taxable for social security from $4,800 to $6,600 and called for a gradual increase in the rate of taxation to 5.65 percent by 1987.

Congress also established the Federal Government in the kind of regulatory role most deplored in advance by the physician and other economic interests that so strenuously opposed the entrance of the Government into the field of medical insurance. The Department of Health, Education, and Welfare is now empowered to police the "utilization" of medical resources and to establish standards for the medical services that are purchased by public funds. With such institutions as Blue Cross and Blue Shield and commercial insurance companies serving as "fiscal intermediaries" between the Federal Government and the vendors of medical care, and with physicians permitted to bill their patients directly for fees for service, the opposition has settled for the new status quo.

The same legislation that established social insurance of medical care for the first time in the U.S. also provided for a massive expansion of Federal subvention of medical care through more traditional public-welfare channels. Title XIX of the Social Security Act offers increased Federal aid to states that will establish a "single and improved" medical care program to replace separate programs for medical assistance to needy children and to the aged, blind and disabled hitherto amplified by Federal funds. Title XIX goes still further. It offers to match local funds laid out to deliver medical care to "medical indigents"—to people "not receiving public assistance but who cannot pay part or all of their medical costs." By July 1, 32 of the 54 jurisdictions (the 50 states, the District of Columbia, Puerto Rico, Guam and the Virgin Islands) eligible for such Federal aid had begun to take steps to qualify for it.

The scope of public medicine in the U.S. under Title XIX is forecast in the qualifying legislation adopted by the State of New York. Medical indigence for a family of four, entitling the family to payment of substantially all its hospital and doctors' bills, is set at an income of $4,500 per year. Depending on family size and other circumstances, families with still higher incomes may qualify for payment of the major portion of their medical costs. At the $4,500 floor 35 percent of the population will qualify for what New Yorkers are calling "medicaid." In New York City, even in advance of the imminent flow of Title XIX funds, city, state and Federal treasuries already finance the medical care of 40 percent of the population.

These figures suggest that Title XIX may ultimately underwrite medical care for a great many more people than Title XVIII. According to the Department of Health, Education, and Welfare, the new legislation reflects "a determination by the American people and the Congress that needed medical care is not to be denied to any person regardless of age because he, individually, cannot afford to pay the costs."

Educational Satellites

The Federal Communications Commission has before it a proposal that would take "a people's dividend," earned by the country's "enormous investment in space," to finance a national educational television system. A "Broadcasters' Non-Profit Satellite Service" would provide transmission services for domestic commercial television. From savings on the costs of the present terrestrial transmission lines would come ample funds to pay for the programming as well as the facilities of noncommercial television.

This proposal "to make the desert bloom" was filed on behalf of the Ford Foundation by McGeorge Bundy, president. Fred Friendly, former president of C.B.S. News and now consultant to the foundation, had a principal hand in its design. It was drafted in response to the commission's call for recommendations on the uses of satellites in the domestic communications system.

The "near-term configuration" of the proposed "BNS" calls for four satellites on stationary orbit (23,600 miles above sea level) serving 11 channels in each continental time zone. Six channels would be hired out to commercial television networks and stations. The revenue would support the other five, three devoted to primary and secondary education, one to university education and one to "cultural and informational programs," including "full and live coverage of significant hearings and debates." A total investment of $80 million would finance the satellites and ground stations for the commercial service and would equip the noncommercial system with eight primary transmitting stations and 750 rebroadcasting stations.

Annual operating and capital charges of $20 million would yield an immediate saving of $45 million on the present transmission costs of commercial television. An initial people's dividend of $30 million from this saving would multiply by five the funds currently available, principally from the Ford Foundation, for the programming of educational television.

The Taxpayer as a Patron

The nation's principal patron of the sciences has now become a benefactor of letters and the arts as well. Through the National Foundation on the Arts and the Humanities, the Federal taxpayer has made the first large grants from a fund of $5.5 million set aside for scholarly and educational enterprises in those fields in the 1966–1967 fiscal year. The appropriation is small compared with the $480 million being disbursed by the National Science Foundation. It augurs a more abundant future, however, when compared with the $3.5 million that established the first Federal commitment to the support of science for its own sake 15 years ago.

Under the chairmanship of Henry Allen Moe, for many years president of the John Simon Guggenheim Memorial Foundation, the governing council of the new humanities foundation has committed more than half of its resources "to discover talented men and women . . . to support, educate, assist and encourage them so that their thinking and personalities may be available to all mankind." For younger scholar-teachers 200 summer fellowships and 100 longer fellowships will be available, and for "mature humanistic scholars, teachers and writers" 50 fellowships. Grants will be made for "interdisciplinary training" of critics, who are said to be "particularly needed on newspapers and journals away from the major metropolitan cities where only one critic covers all the arts."

For "the neglected stepchildren of our national education enterprise"—the historical societies and museums that annually attract several times as many people as "attend all baseball games of all 20 major-league teams"—the council plans a major program. Significant investment will be made also in "the recovery of the great legacy of American literature as a whole." The foundation will bestow a seal of approval—its own Constellation Library colophon, "after the famous American frigate of that name, implying victories of the mind and spirit and carrying the flag of American cultural accomplishment to all the world"—on "definitive editions of works of our best literature."

Proteins Start Here

For several years biochemists have been searching for the "signal" that tells the protein-synthesizing mechanism of the cell when to start building a new protein chain—or alternatively when a chain is completed. Theoretically only one signal or the other is needed, since it could play the same role as a period that separates two sentences. A period can be regarded not only as a sign that a sentence has been completed but also as a sign that a new sentence is about to begin. Some such punctuation is needed because when a molecule of "messenger" ribonucleic acid (RNA) transcribes genetic information from its primary site—deoxyribonucleic acid (DNA)—it often embodies the code for more than one protein.

Evidence has now been found in the colon bacterium *Escherichia coli* that the start of each protein chain is signaled by a biochemical initiator. Conceivably no termination signal is needed, but this remains to be demonstrated. The evidence for an initiator is reported in the *Proceedings of the National Academy of Sciences* by Mario R. Capecchi of Harvard University.

Earlier work with viruses that infect bacteria had shown that certain proteins that form the coat of the virus have an extra amino acid unit at one end if they are synthesized in cell-free systems; the extra unit is missing from viral protein that has grown in living cells. The extra unit is formylmethionine, which has one more carbon atom than methionine, one of the 20 common amino acids that enter into the synthesis of proteins. Evidently formylmethionine is clipped from the chain by an enzyme before the protein can function as the virus's normal coat protein.

With this and other evidence as a lead Capecchi designed a series of experiments to see if the proteins synthesized in cell-free extracts derived from *E. coli* might also contain formylmethionine as an extra end unit. It was known that the normal proteins from intact cells of *E. coli* lack this unusual amino acid. Capecchi found that in cell-free systems formylmethionine is indeed incorporated into *E. coli* protein chains at the rate of about one unit per chain. The living cell evidently has enzymatic machinery, missing in the cell-free system, that removes formylmethionine from the newly synthesized proteins. Capecchi thus concludes that formylmethionine—when attached to the carrier molecule "transfer" ribonucleic acid—acts as the initiator of most, if not all, *E. coli* proteins. The search for a terminator signal is being continued.

Unsafer Everywhere Else

Among highly motorized nations the safest place in which to drive a car is New Zealand, followed closely by the U.S. However, the combined fatality rate for vehicle occupants and pedestrians—the usual form in which motor vehicle fatalities are presented—shows the U.S. record to be slightly better, per 100,000 registered vehicles, than that of any comparable country. The most dangerous place in which to drive is West Germany and the most dangerous for pedestrians is Britain. These and other statistics in driving hazards appear in the *Statistical Bulletin* published by the Metropolitan Life Insurance Company.

Twelve countries now have 15 or more motor vehicles per 100 population; the U.S. tops the list with 43 vehicles per 100. Considering these 12 countries, the four with the highest death rate per 100,000 registered vehicles are West Germany (159.8 deaths per 100,000), Switzerland (153), France (112.9) and Denmark (101.8). The four safest countries are the U.S. (52.6 deaths per 100,000), New Zealand (53.8), Canada (74.6) and Sweden (76.1).

The spread in mortality rates narrows considerably if the figures are based on units of population. West Germany is still high with 25 motor vehicle deaths per 100,000 population, closely followed by Australia (24.5), Canada (23.6) and the U.S. (23.1). On

this basis the four safest countries are Northern Ireland (12.4), England and Wales (13.5), Scotland (14.1) and New Zealand (16.5).

Pedestrian deaths as a percent of all motor vehicle fatalities show a range from 17 percent (for the U.S.) to 40 percent (Britain). A higher figure, 56 percent, is recorded in Italy, which has only nine vehicles per 100 population and thus does not rank among the first 12 countries in automobile ownership. Japan, which has still fewer cars (four per 100), has by far the highest overall death rate per 100,000 registered vehicles: 402.2. The statistics are all for 1963.

Beware of the Dog and Cat?

Dogs and cats may constitute "a considerable public-health hazard," three investigators in England have concluded after studying the infection of humans with intestinal worms that are quite common in the household pets. The eggs of the worms, *Toxocara canis* and *T. cati,* can pass to humans; they develop into larvae that travel in the bloodstream to various parts of the body. When a larva dies, it apparently stimulates the growth of a granular nodule around it. Writing in the *British Medical Journal,* A. W. Woodruff, B. Bisseru and J. C. Bowe cite evidence that toxocaral infection may be causally connected with poliomyelitis and epilepsy.

The three investigators developed a skin test that reveals a past toxocaral infection. On the basis of earlier reports linking the larvae to several diseases, including one case of poliomyelitis, they administered the test to former poliomyelitis patients. Of 191 such patients, 13.6 percent gave evidence of past toxocariasis. In contrast, only 2.1 percent of 329 people in a control group reacted positively to the skin test. The authors suggest that the larvae, in migrating out of the digestive tract, may carry poliomyelitis virus with them, facilitating its entry into the brain and nervous tissues.

On the hypothesis that nodules caused by the dead larvae might give rise to lesions in the brain, Woodruff, Bisseru and Bowe also looked for a connection between toxocaral infections and epilepsy. Administering the skin test to 349 patients with epilepsy, they got positive reactions in 7.5 percent of the tests, or more than three times the incidence in the control group. The possibility that the larvae can cause epilepsy was strengthened by other find-

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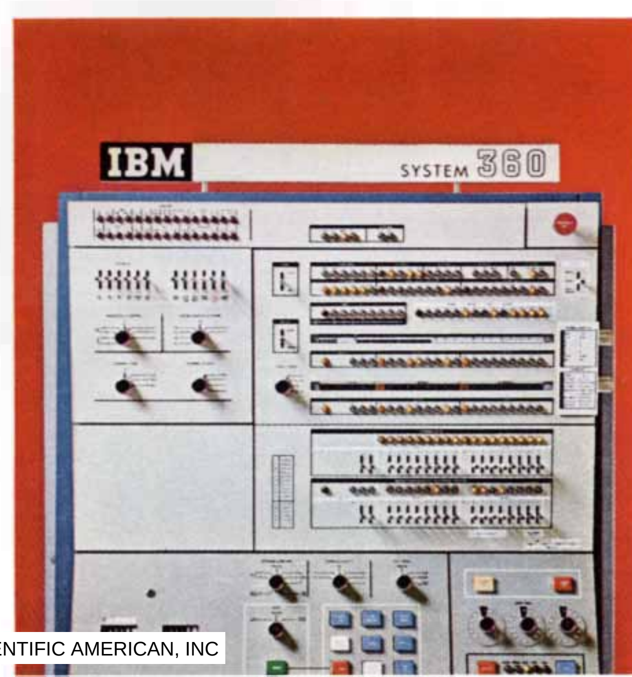

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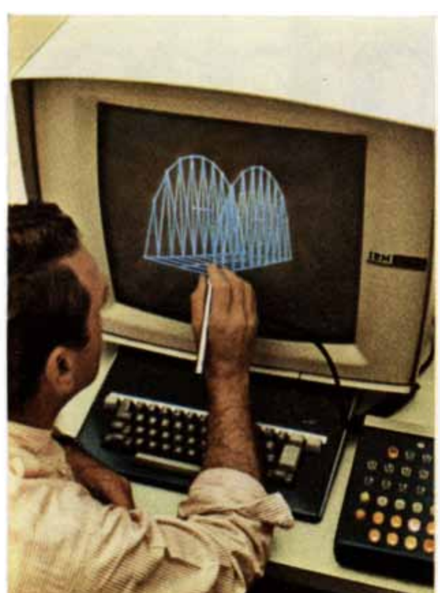

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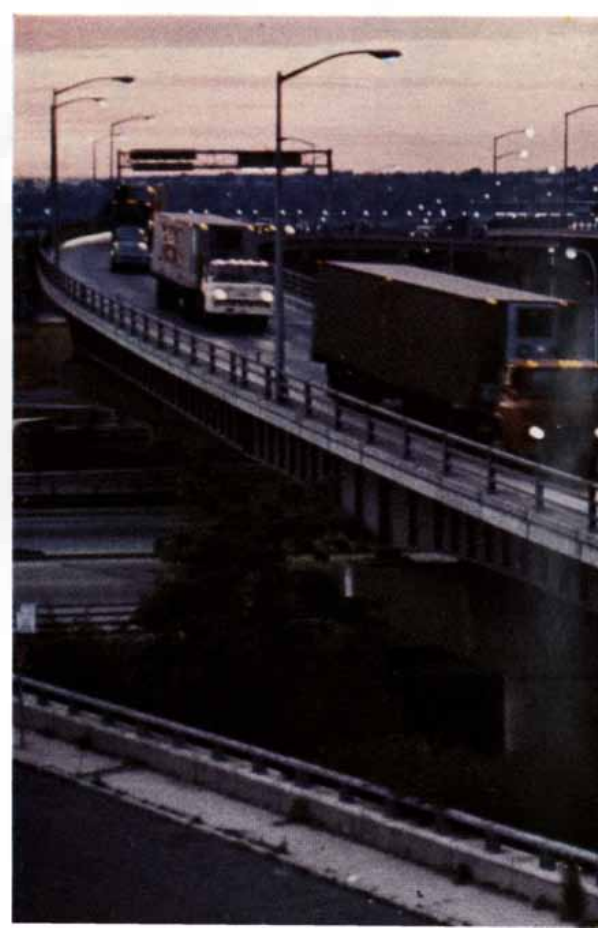

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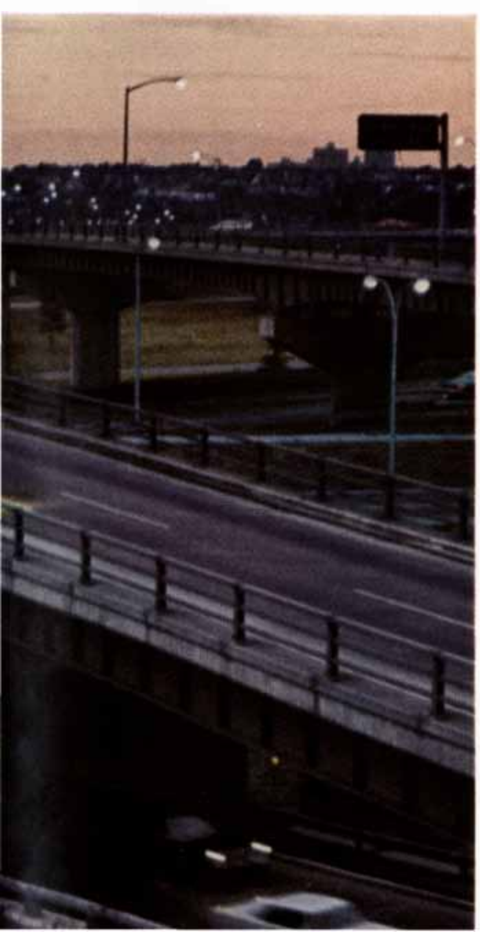
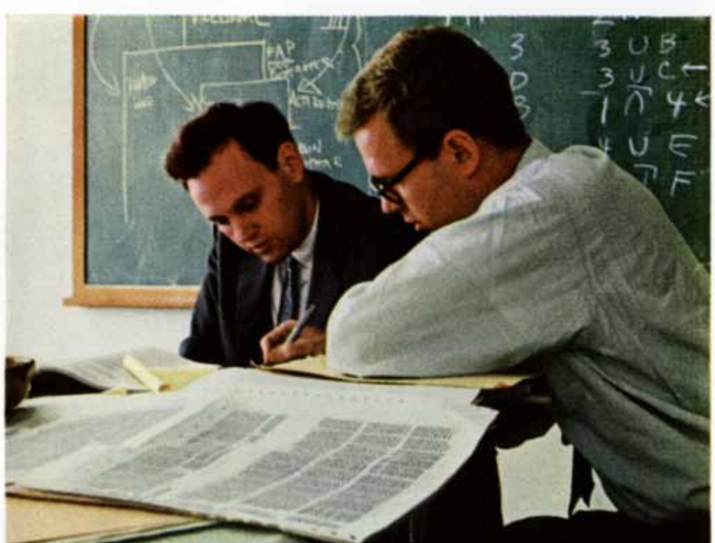


Traffic flow is one of many problems simulated with general-purpose programs.



IBM programs provide solutions to mathematical and statistical problems.

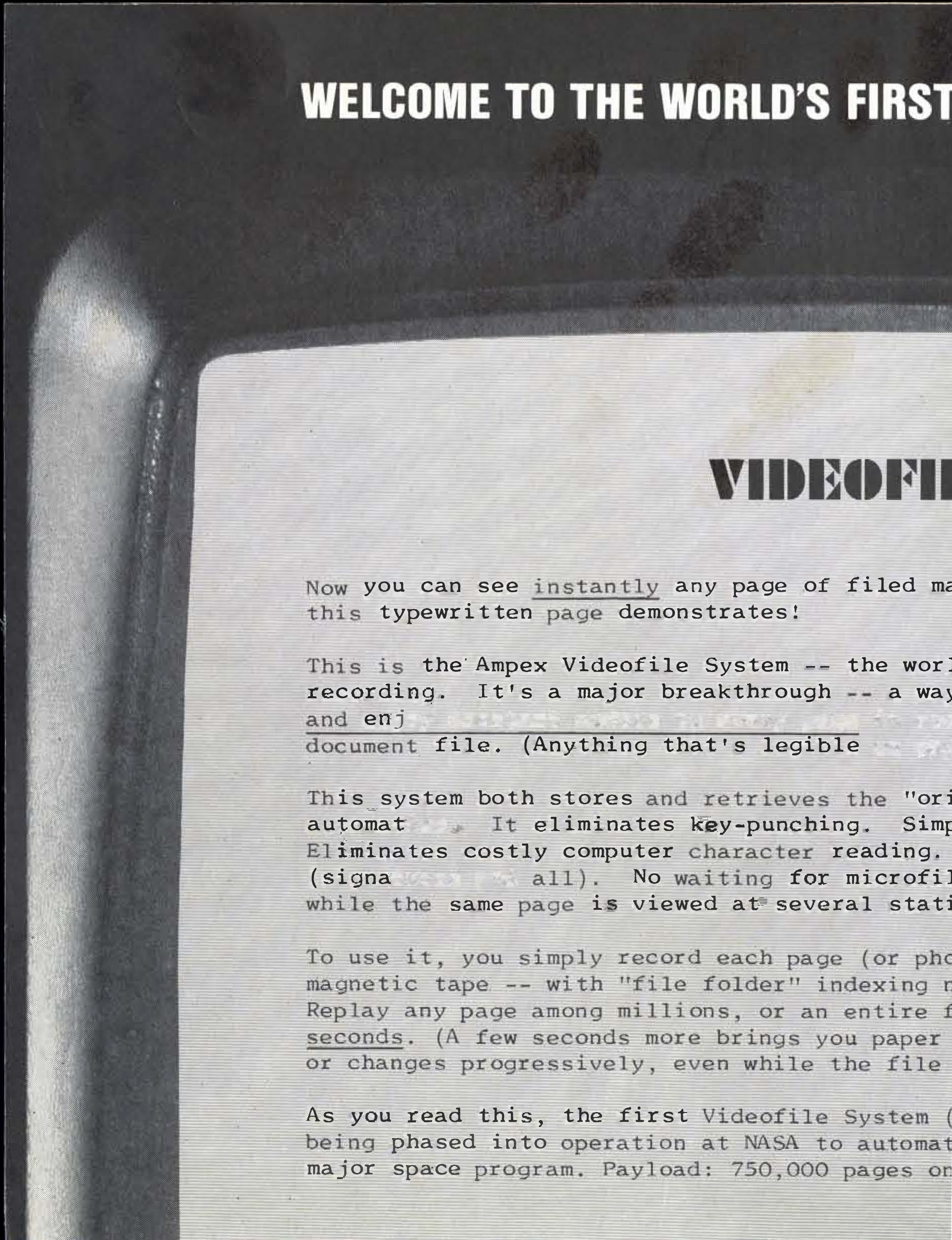
ings. A family history of epilepsy was found in only one (3.8 percent) of the 26 epileptics with positive skin tests but in 6.8 percent of the others. And a larger proportion of those with positive tests had had a dog or a cat in their households.

Studies in England and the U.S. indicate that one out of five household dogs and cats harbors the intestinal worm in question, and the proportion is apparently much higher in the Tropics. The investigators conclude that toxocariasis affects considerable numbers of people, that it can probably spread poliomyelitis and cause epilepsy and that it may well be connected with a number of other diseases, particularly in the Tropics.

Fallen Christmas Star

The odds against any person on the earth being struck by a meteorite, calculated as little better than three chances in 100 for the period 1900–1999, remained unaltered last year when at twilight on Christmas Eve a meteorite flashed northward across England. According to a recent article in *Sky and Telescope,* however, it was a near thing. The meteorite burst into fragments at low altitude and dumped at least 85 pieces with a total weight of 103 pounds on the Midlands manufacturing town of Barwell, near Birmingham. Although no one in Barwell was hit, two windowpanes were broken, three roofs were penetrated and the hood of a car was dented.

The brilliance of the fireball produced by the Barwell meteorite and the loudness of the explosion at its breakup attracted attention over a large part of central England, but most observers attributed both the light and the sound to jet aircraft. Not until more than a week after the event, when local police sent fragments collected by townspeople to the University of Leicester, was it realized that a meteorite had fallen. The British Museum (Natural History) thereupon offered a bounty of $1.40 per ounce for any fragments that could be located. An earnest collecting effort began; the largest single piece to be recovered weighed 17 pounds. In the absence of identification and subsidized recovery the Barwell meteorite might never have been found. A stony meteorite of the type called a chondrite, it is subject to rapid oxidation; its fragments would have become indistinguishable from fieldstone within a few weeks.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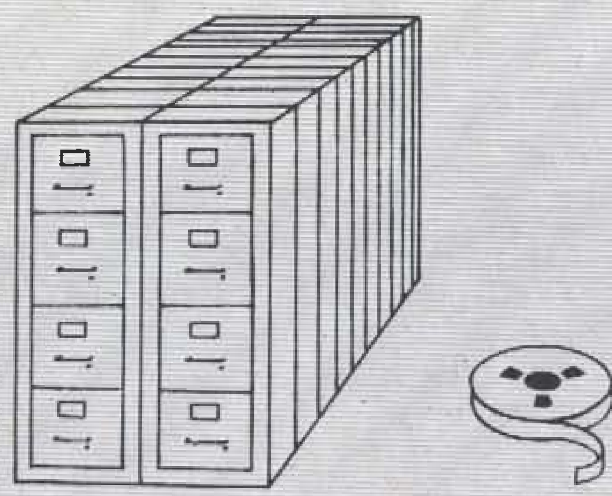

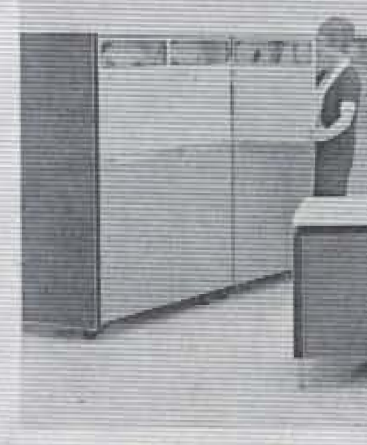

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System Analysis and Programming

The process of stating a problem in a language that is acceptable to a computer is primarily intuitive rather than formal. A specific example of the process is given

by Christopher Strachey

It is a profoundly erroneous truism, repeated by all copy-books and by eminent people when they are making speeches, that we should cultivate the habit of thinking of what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them. Operations of thought are like cavalry charges in a battle—they are strictly limited in number, they require fresh horses, and must only be made at decisive moments.

—Alfred North Whitehead

This article is about how to get a computer to do what you want, and why it almost always takes longer than you expect. What follows is not a detailed report on the state of the art of programming but an attempt to show how to set about writing a program. The process of writing a program is primarily intuitive rather than formal; hence we shall be more concerned with the guiding principles that underlie programming than with the particular language in which the program is to be presented to the machine.

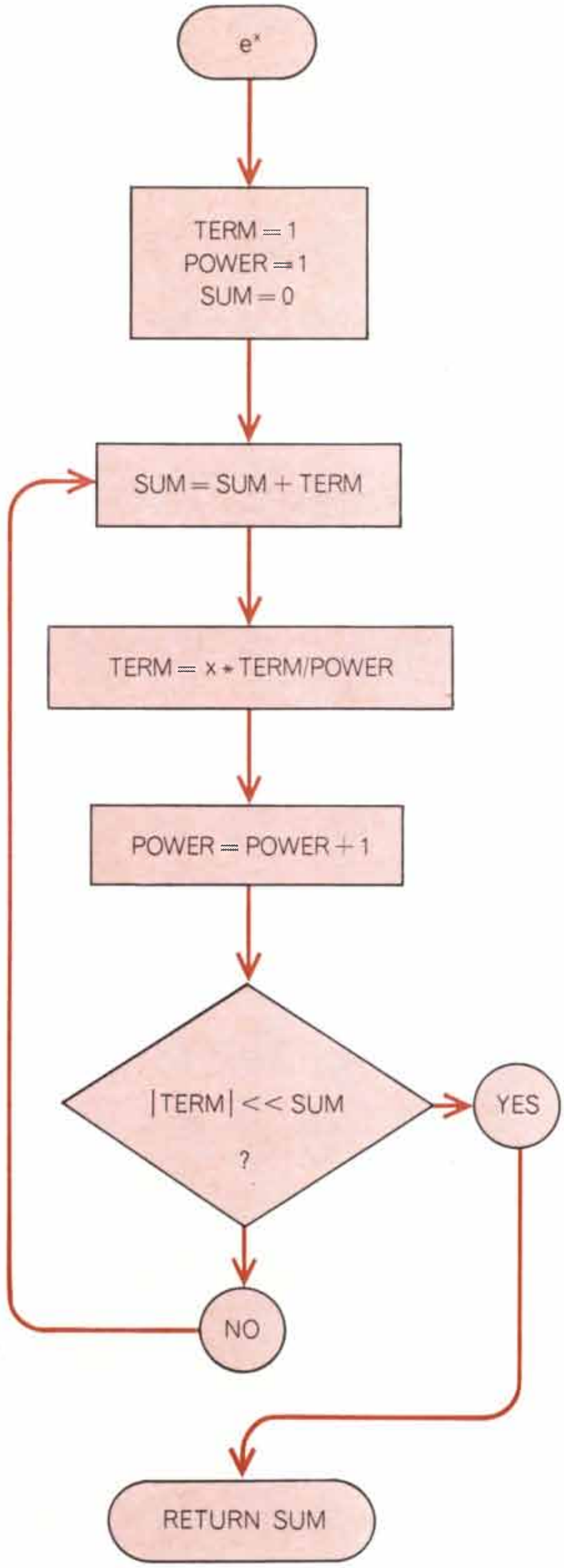
We shall start with a specific example of a programming problem that is decidedly nontrivial and yet sufficiently simple to be understood without any previous knowledge of programming. I have chosen an unorthodox approach to the problem, one that will look strange to many professional programmers. This approach enables us to tackle an example that would be much too elaborate to explain otherwise.

Our problem is to program a computer to play checkers. How should we set about it? There are two main aspects to the problem. To equip the computer to deal with the game at all we must find a way to represent the board and positions on it and furnish the computer with a program for identifying legal moves and making them. This is a programming problem. Secondly, we must provide the machine with a method of selecting a suitable move from the ones available. This is mainly a problem in game-playing. Arthur L. Samuel of the International Business Machines Corporation has studied this game-playing aspect extensively and with considerable success [see "Artificial Intelligence," by Marvin L. Minsky, page 246]. Here, however, since we are concerned with programming rather than game-playing, we shall content ourselves with a simple general strategy and leave most of the details unsettled.

The usual approach to writing a program, particularly for a complex problem, divides the process into two stages. The first of these is called system analysis. It involves analyzing the task to decide exactly what needs to be done and adopting an overall plan. Once the general outline of the work to be performed has been decided on, the second stage is to write the required operations in a form suitable for the computer. This involves a large number of more detailed decisions (for example how information is to be represented in the machine and how the representations are to be stored). The detailed form of the program will depend on the particular computer to be used.

Confusion has developed about the naming of these two stages. Some programmers reserve the term "programming" for the second stage; others call the first stage "programming" and the second stage "coding"; still others use the term "programming" for the entire process—stages one and two. My own view is that the distinction between system analysis and programming is not a very useful one. If the system analysis were carried through to a description of the program outline in a slightly more rigorous language than is used at present, it should be possible to relegate the whole of the remaining process of producing a detailed program in machine language to the computer itself.

ORTHODOX APPROACH to the problem of writing a computer program is illustrated on the opposite page. The problem in this example is comparatively simple: to find the function e^x by summing the series $1 + x + x^2/2! + x^3/3! + \ldots$ until the terms become negligible. The process of writing a program to solve such a problem is usually divided into two stages. The first stage, sometimes called system analysis, involves analyzing the task to decide exactly what needs to be done and adopting an overall plan; this stage is represented by the block diagram at left. The second stage, called programming by some programmers and coding by others, involves writing the required operations in a form suitable for the computer. The problem in question is expressed in three different programming languages at right. The diamond-shaped box in the block diagram contains a "decision function"; the straight vertical lines before and after the word "term" signify "absolute value of," and the symbol $<<$ means that "$|$term$|$" is negligible compared with "sum." In CPL (Combined Programming Language) the expression "value of" governs the immediately following statement; "repeat" governs the immediately preceding statement, and the symbols § and $ act as statement brackets. In both CPL and ALGOL the operator ":=" stands for assignment: the quantities on the right of this operator are evaluated and simultaneously assigned to the variables on the left. The symbol * in FORTRAN is a multiplication sign.



a

CPL

```
let Exp [x] = value of
      § let t, r, s = 1, 1, 0
        t, r, s : = xt/r, r+l, s+t
        repeat until t << s
        result is s §
```

b

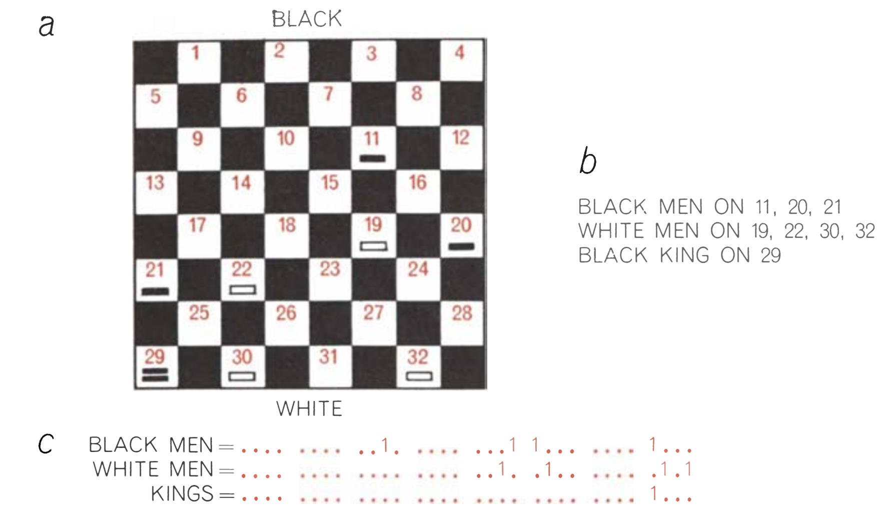
ALGOL

```
real procedure Exp (x);
value x; real x;
begin real term, power, sum, q;
   term: = power: = q: = 1;
   sum = 0;
   for sum = sum + term while q >10 −12 do
      begin term: = x × term/power;
         power: = power + 1;
         q: = abs (term/sum) end;
   Exp: = sum;
end
```

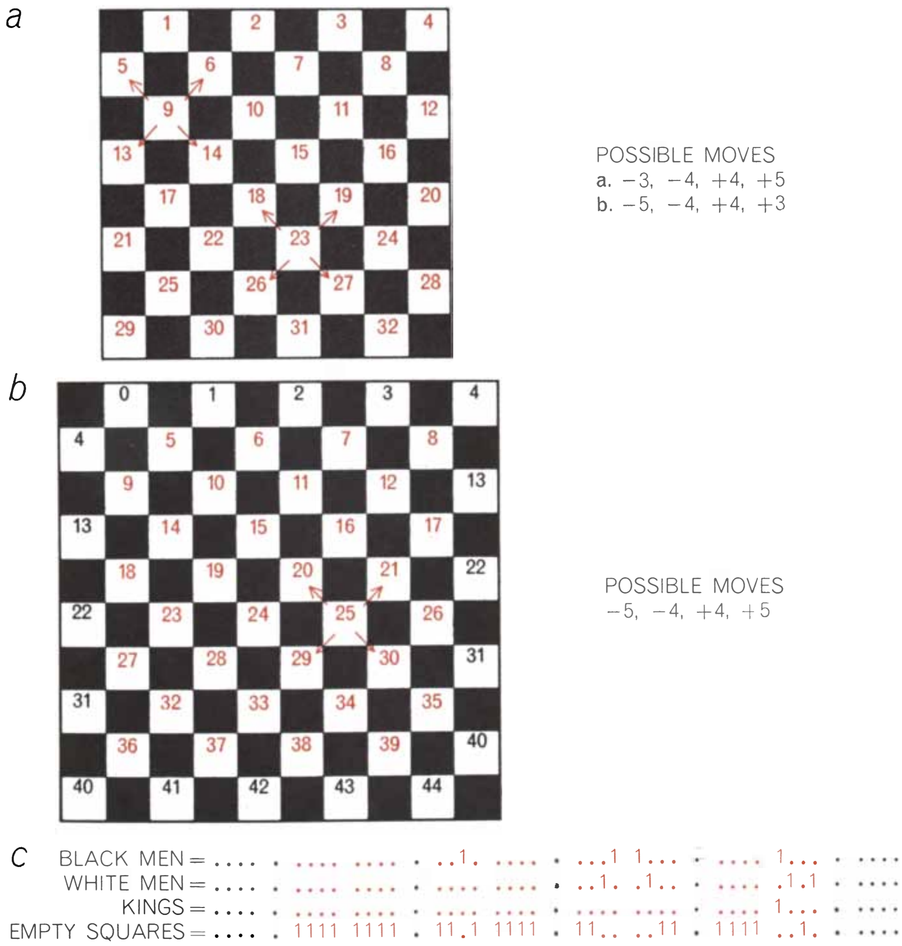
c

FORTRAN IV

```
   FUNCTION  EXP (X)
   TERM = 1.
   POWER = 1.
   SUM = 0.
10 SUM = SUM + TERM
   TERM = X * TERM/POWER
   POWER = POWER + 1.
   IF (ABS (TERM/SUM) .GT. 10E − 12 GO TO 10
   EXP = SUM
   RETURN
   END
```



POSITIONS on a checkerboard can be represented in a computer in two different ways. To describe a particular position one has the choice of specifying either what is on each square (*a*) or where the pieces that are still in play are located (*b*). An equivalent alternative to *a* is given in *c*, which uses only binary numbers. Three binary digits, or "bits," are needed to specify each square: one to show the presence of a black man or king, another to show the presence of a white man or king and a third to show the presence of kings of either color.



MOVES on a checkerboard can be represented using the numbering scheme of an ordinary checkerboard (*a*), but this is inconvenient, as there are two kinds of squares (on alternate rows), which need different rules. Arthur L. Samuel of the International Business Machines Corporation devised a neat method of avoiding this difficulty. By extending the board with rows and columns that are not used and renumbering the squares, he produced a scheme in which the possible moves are similar for all squares on that part of the board which is actually used (*b*). The position shown at the top of this page is represented in this new scheme of notation in *c*. Empty squares are indicated by 1's for all the squares on the board proper.

Let us get on to the problem of programming a computer to play checkers against an opponent. How shall we represent the relevant features of the game, and what kind of operations do we want to be able to perform on them? A good working rule is to start with the operations and allow them to determine what it is you need to represent in the machine. In this case we clearly require, to begin with, representations of positions and moves and of the values associated with them.

We can approach the kind of precision the computer requires and still avoid getting bogged down in premature detail by using a functional notation. We let *P* stand for a position and agree to include in *P* not only the number and arrangement of the pieces on the board but also various other important facts such as which player is to move. The value of a position can be expressed by a function PositionValue(*P*). The value of any move (say *M*) obviously depends on the position from which it is made; therefore we must specify the position in writing the function MoveValue(*M*,*P*). Next, in order to be able to look ahead and examine the possible consequences of moves, the computer will need a third function: MakeMove(*M*,*P*), with *P* representing the position from which the move is made. The result of this function is the new position produced by the move. Finally, the program needs a fourth function to find all the legal moves that can be made from a given position: LegalMovesFrom(*P*). This function has as its result a list of moves.

These four functions, together with the two types of object (*P* and *M*), are sufficient to specify the kernel of our checkers program. There are two players in a game of checkers (in our case the machine and its opponent), and a position that is good for one will be bad for the other. We must therefore make our idea of the value of a position more precise by saying that PositionValue(*P*) gives the value of the position *P* to the player who has to move from it. We can plausibly assume that the value of the position *P* to the other player is the negative of this; that is, if the value of a position to one player is v, its value to the other will be $-v$. (This assumption is expressed in the terms of game theory by saying that checkers is a zero-sum game.)

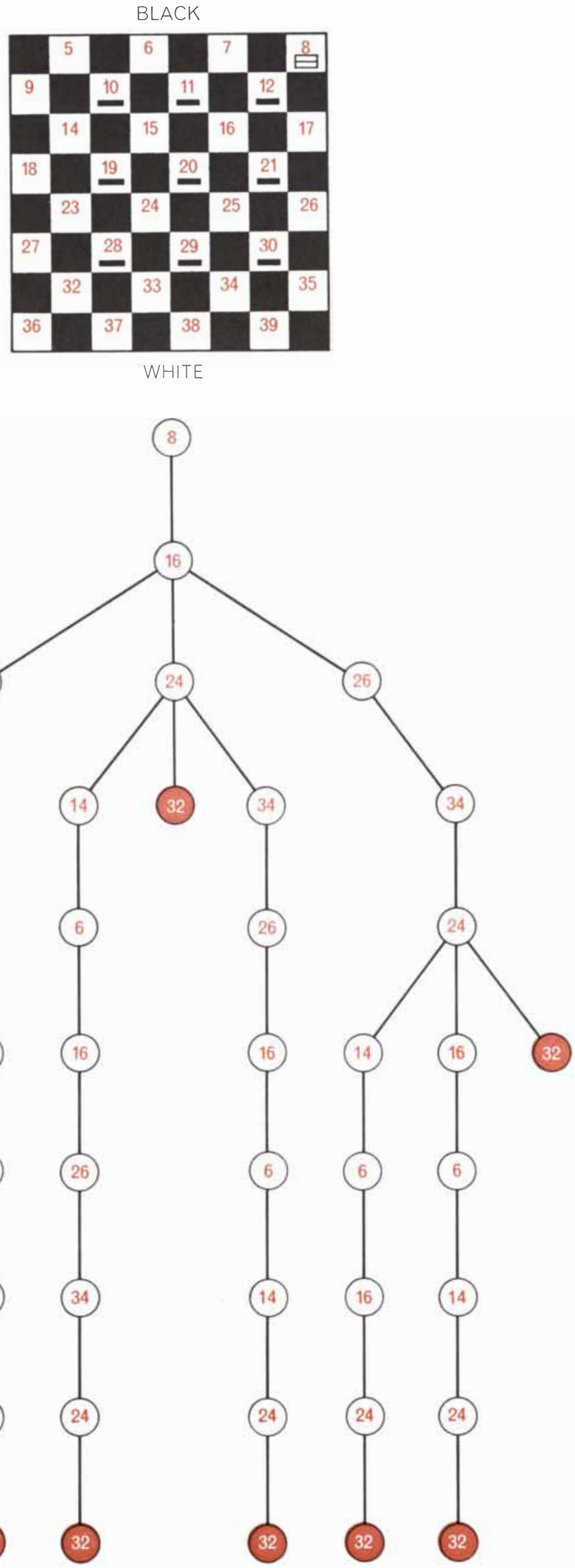
Next we can define the value of a move to the player who makes it as the value *to him* of the resulting position. Suppose the result of making the move

M from the position P is the position P'. Remembering that it is the opponent who has to make the move from P', we can see that the value of the move M to the player who makes it will be $-$PositionValue(P'). Thus in our notation we can define the value of a move as follows: MoveValue(M,P) = $-$PositionValue[MakeMove(M,P)]. This formal statement could be paraphrased by saying that to value a move for yourself you make it, find the value of the resulting position to your opponent and change its sign.

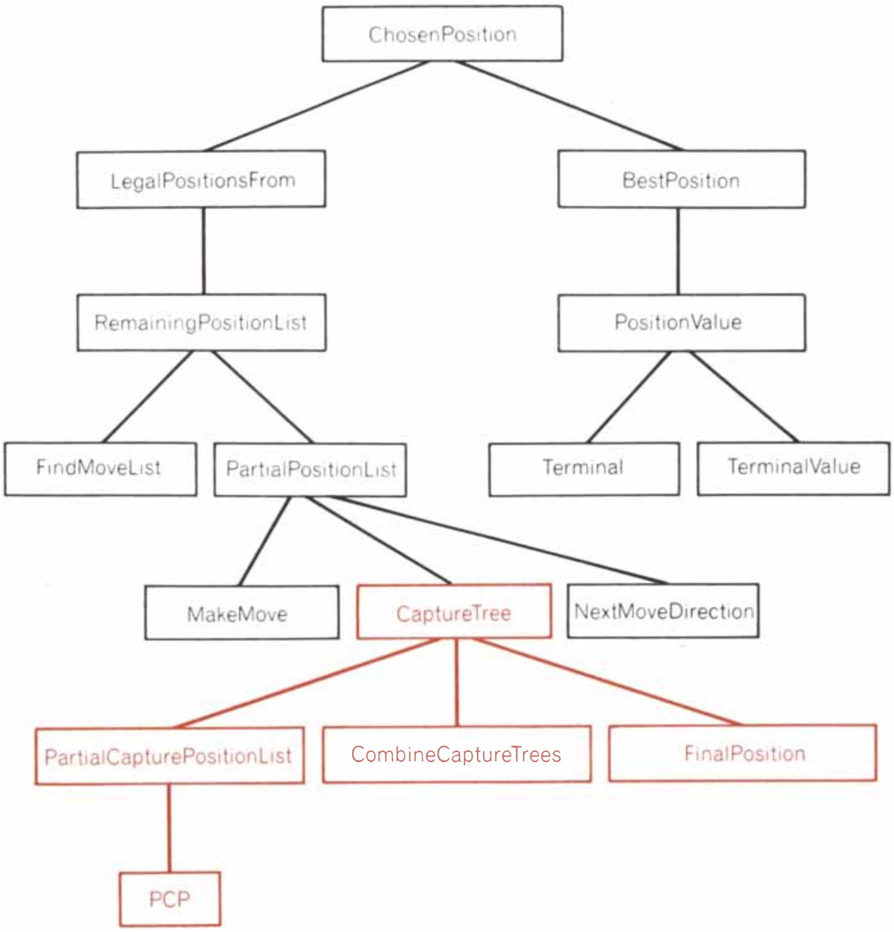
How shall we find the value of a position? The basic procedure of the game is to explore all your possible moves and all possible replies by the opponent to some depth and evaluate the resulting positions. Let us call these "terminal" positions and say that their values are produced by the function TerminalValue(P). This function makes an immediate assessment of a position (in terms, perhaps, of such factors as the number of pieces still in play, their mobility, the command of the center of the board and so forth) without any further look-ahead. We can now say that if P is a terminal position, its value is TerminalValue(P), and that if it is not, its value is that of the best legal move that could be made from it. Note that the question of whether a position is terminal or not may depend not only on the position itself but also on what depth (d) the look-ahead has reached. This is necessary in order to put some limit on how far the machine looks ahead.

The definitions we have been writing are in fact circular (for example, the definition of PositionValue involves the use of MoveValue and vice versa), and the functions are called recursive, because each is defined in terms of the others. This circularity is no disadvantage; indeed, it makes it possible to start right in the middle of things, to set up a number of functions whose purpose is only intuitively understood at the beginning and to define each of them in terms of the others. This recursive, or hierarchical, approach to programming is by far the simplest method of handling complicated operations, since it allows them to be broken up into smaller units that can be considered separately.

We have now constructed a general game-playing scheme without having decided on either the details of the strategy or the structure of the game itself. We can complete the outline of our program by deciding on the representation of positions and moves and defining four functions. The functions Legal-



CAPTURE "TREE" depicts all the possible "partial capture moves" for a given piece after the first such move. In checkers a move is not complete until no more captures can be made. A maximum of nine captures in a single move is possible, as shown in this example. Capture-move situation, like that in the main game, can be programmed by using "recursive" functions, that is, functions that are defined in a circular manner in terms of other functions. Program for this situation is incorporated in the complete checkers program on page 117.



HIERARCHICAL STRUCTURE of the author's checkers program is evident in this diagram. Since there is a limit to the size and complexity of a problem one can keep in mind at one time, it appears that the best way to deal with large and complicated problems is to treat fairly sizable operations as separate units and then combine them hierarchically. The logical function "ChosenPosition" is defined recursively in terms of two other functions: "LegalPositionsFrom" and "BestPosition." The function "LegalPositionsFrom" deals with the problem of finding legal positions on the checkerboard at a given point in the game; all the functions that branch out from "LegalPositionsFrom" treat various aspects of this problem. The part of this major branch that deals with capture moves, for example, is in color. The function "BestPosition" and all the functions that branch out from it deal with the problem of choosing the best position from the list supplied by "LegalPositionsFrom."

MovesFrom(P) and MakeMove(M,P), together with the form of P and M, will determine the nature of the game, and the functions Terminal(P,d) and TerminalValue(P) between them will determine the strategy.

The selection of ways to represent objects in the computer is an art, and there is little we can do in a systematic fashion to decide the best way. The main requirements are that the representation should be as compact as possible and yet as easy as possible to manipulate.

For representing the various positions on a checkerboard we have two distinct possibilities. To describe a particular position we could either specify whether each of the 32 available squares on the board is or is not occupied, and if it is, by what, or we could merely give the locations of the pieces still in play. The first of these alternatives is more convenient from the standpoint of finding the legal moves, because it makes it easier to discover which squares are unoccupied [*see top illustration on page 114*].

When we come to a detailed consideration of the representation of moves, we find that the numbering of squares on the ordinary board is inconvenient because there are two kinds of squares (on alternate rows) that need different rules. Samuel devised a neat method of avoiding this difficulty. By extending the board with rows and columns that are not used and renumbering the squares, he produced a scheme in which the possible moves were similar for all squares on that part of the board which is actually used [*see bottom illustration on page 114*].

All the possible moves (other than those in which pieces are captured) fall into four types, each of which can be represented by a word (consisting of 45 bits, or binary digits) that can specify any move of its type. Within the framework of the scheme of notation we have been using it is also a simple matter to represent capture moves and the promotion of men to kings.

It would go beyond the scope of this article to discuss all the details of a working checkers program. The main outlines of the process of writing such a program should, however, be apparent by now. The first step is to have a vague idea of how to solve the problem. The second step is to specify the operations needed to carry out this initial plan, formalizing it by giving names to the objects on which these operations are to act. The third step is to clarify the definitions of the objects and to settle on a representation for each of them. These representations should be determined primarily by the operations to be performed on the objects. Once the representations have been decided on, the component operations can be defined more precisely in terms of them. One can then go on to refine the program, correcting errors or deficiencies that may show up in the representations and adjusting the operations accordingly.

At this stage the major intellectual

COMPLETE CHECKERS PROGRAM is given in the left-hand column on the opposite page. The language used in the program is an informal and somewhat extended version of CPL. The names of the logical functions that are specific to this particular program ("ChosenPosition" and so on) were selected to be suggestive of the operations they govern. A list of the primitive, or generalized, functions and the specific data structures used in the program is provided in the right-hand column. The chief omissions from the program are the input and output arrangements and the functions that define the game-playing strategy [Terminal (P,d) and Terminal Value (P)]. The program has not been debugged on a machine and so, in accordance with the views expressed in the article, probably still contains some errors; interested readers may like to look for them. The general notation "Condition → A,B" is a conditional expression whose value is A if the condition is satisfied (that is, if it is true) and B otherwise. The section that deals with capture moves is in color.

```
ChosenPosition(P) = value of
      § let L = LegalPositionsFrom(P)
        if Null(L) then Resign
        let (p,v) = BestPosition(NIL, − ∞,L,0)
        result is p $

BestPosition(P,V,L,d) = Null(L)→( P,V), value of
      § let (p,l) = Next (L)
        let v = − PositionValue(p,d + 1)
        result is (v > V) → BestPosition(p,v,l,d),
                            BestPosition(P,V,l,d) $

PositionValue(P,d) = Terminal(P,d) → TerminalValue(P), value of
      § let L = LegalPositionsFrom(P)
        let (p,v) = BestPosition(NIL, − ∞,L,d)
        result is v $

LegalPositionsFrom(P) = value of
      § let L = RemainingPositionList(P,Capture,5)
        result is Null(L)→RemainingPosition List(P,NonCapture,5),L $

RemainingPositionList(P,C,s) =
        PartialPositionList(P,C,s,FindMoveList(P,C,s) )

PartialPositionList(P,C,s,L) =
        Null(L)→( (s = −5)→NIL,
                  RemainingPositionList(P,C,NextMoveDirection(s) ),
             value of
      § let ϕ = SingleDigitFrom(L)
        let Ip = MakeMove(P,C,s,ϕ)
        let I = (C = Capture)→CaptureTree(Ip),
                              FinalPosition(Ip)
        result is Join (I,PartialPositionList(P,C,s,L − ϕ) ) $

NextMoveDirection(s) = (s = 5) → 4, ( (s = 4) → − 4, − 5)

FindMoveList(P,C,s) = value of
      § let (X,Y,K,σ) = P
        let Empty = ∼ X ∧ ∼ Y ∧ Board
        let ψ = (C = Capture) → (Shift(Empty,σs) ∧ Y),Empty
        let ϕ = Shift(ψ,σs) ∧ X
        result is (s > 0) → ϕ,ϕ ∧ K $

MakeMove(P,C,s,ϕ) = value of
      § let (X,Y,K,σ) = P
        let ψ = (C = Capture) → Shift(ϕ, − σs),NIL
        let θ = (C = Capture) → Shift(ψ, − σs),
                                Shift(ϕ, − σs)
        let Xk = Null(ϕ ∧ K) → (θ ∧ LastRows),(θ − ϕ)
        result is ( (X − ϕ + θ),(Y − ψ),(K − ψ ∧ K + Xk),σ,θ) $

FinalPosition(Ip) = value of
      § let (X,Y,K,σ,ϕ) = Ip
        result is (Y,X,K, − σ) $

CaptureTree(Ip) = value of
      § let L = PartialCapturePositionList(Ip)
        result is Null(L) → (FinalPosition(Ip) ),
                            CombineCaptureTrees(L) $

PartialCapturePositionList(Ip) = value of
      § let (X,Y,K,σ,ϕ) = Ip
        let P = (X,Y,K,σ)
        result is MinList(PCP(P,ϕ,5),PCP(P,ϕ,4),
                          PCP(P,ϕ ∧ K, − 4),PCP(P,ϕ ∧ K, − 5) ) $

PCP(P,ϕ,s) = value of
      § let (X,Y,K,σ) = P
        let ψ = Shift(ϕ, − σs) ∧ Y
        let Empty = ∼ X ∧ ∼Y ∧ Board
        let θ = Shift(ψ, − σs) ∧ Empty
        let Xk = Null(ϕ ∧ K) → (θ ∧ LastRows),(θ − ϕ)
        result is Null(θ) → NIL,
                  ( (X − ϕ + θ),(Y − ψ),(K − ψ ∧ K + Xk),σ,θ) $

CombineCaptureTrees(L) = Null(L) → NIL, value of
      § let (Ip,l) = Next (L)
        result is Join(CaptureTree(Ip),CombineCaptureTrees(l) ) $
```

PRIMITIVE FUNCTIONS

a LIST FUNCTIONS

L	LIST
Null(L)	TRUE IF L IS THE EMPTY LIST (NIL), FALSE OTHERWISE
Head(L)	FIRST MEMBER OF L
Tail(L)	WHAT REMAINS OF L AFTER Head(L) IS REMOVED
Next(L)	LIST WHOSE MEMBERS ARE Head(L) AND Tail(L)
Join(L_1,L_2)	A SINGLE LIST FORMED FROM THE MEMBERS OF L_1 AND L_2
MinList(L_1,L_2...)	A SINGLE LIST FORMED FROM THE MEMBERS OF SEVERAL LISTS; ALSO LEAVES OUT NULL LISTS AND REPETITIONS

b BIT-STRING FUNCTIONS

$\sim$	NOT
$\wedge$	AND
$\vee$	INCLUSIVE OR
$x + y$	SAME AS $x \vee y$
$x - y$	SAME AS $x \wedge (\sim y)$
SingleDigitFrom(x)	A BIT-STRING OF THE SAME LENGTH AS x WITH A SINGLE 1 IN A POSITION CORRESPONDING TO ONE OF THE 1'S IN BIT-STRING x
Shift(x,n)	THE BIT-STRING x SHIFTED n PLACES TO THE RIGHT. IF $n < 0$, THE SHIFT WILL BE TO THE LEFT. DIGITS THAT ARE SHIFTED OFF THE END OF THE BOARD ARE LOST. DIGITS SHIFTED ONTO THE BOARD ARE 0'S.

c STRATEGY FUNCTIONS

Terminal(P,d)	TRUE IF P IS TERMINAL, FALSE OTHERWISE
TerminalValue(P)	VALUE OF P (COMPUTED WHEN LOOK-AHEAD BEYOND P IS UNDESIRABLE)

DATA STRUCTURES

a 45-BIT STRINGS

X	PLAYER'S MEN AND KINGS
Y	OPPONENT'S MEN AND KINGS
K	KINGS ON BOTH SIDES
ϕ	SQUARE MOVED FROM
ψ	CAPTURED PIECE (IF ANY)
θ	SQUARE MOVED TO
Board	1'S ON BOARD SQUARES, 0'S ELSEWHERE
LastRows	1'S ON SQUARES NUMBERED 5, 6, 7, 8, 36, 37, 38, 39

b POSITIONS

σ	NEXT PLAY $\sigma = +1$: BLACK TO PLAY $\sigma = -1$: WHITE TO PLAY
P,p	ORDINARY POSITIONS WITH COMPONENTS X, Y, K, σ
Ip	INTERMEDIATE POSITIONS WITH COMPONENTS X, Y, K,σ,ϕ, WHERE ϕ INDICATES THE PIECE THAT CAN MOVE

c MISCELLANEOUS

C	CAPTURE OR NONCAPTURE
s	DIRECTION OF MOVE $s = 5$: FORWARD, LEFT $s = 4$: FORWARD, RIGHT $s = -4$: BACKWARD, LEFT $s = -5$: BACKWARD, RIGHT
V,v	POSITION VALUE
d	DEPTH OF LOOK-AHEAD

work of the program seems to be finished. We have specified precisely what we want the computer to do. The rest—converting the program into instructions for the computer—should be merely routine. Unfortunately it does not quite work out that way, and anyone who has not had the experience of using a computer will be unpleasantly surprised by the amount of time and effort that is still needed.

In the first place, the computer is unable to accept directly the rather sophisticated kind of instructions we should like to give it. It is almost certain that we shall have made use of operations that are too much for any computer. To get around the inability of the machine to do directly what we want, we can write our program in a standard programming language and make the machine translate this into its own much simpler code. This seems an excellent use of a computer to do the donkey work for us, but unfortunately it does not get rid of all the labor. We have to do a good deal of apparently irrelevant and *ad hoc* work to force the program into a form suitable for existing programming languages.

There are now a considerable number of these programming languages: FORTRAN, ALGOL and MAD (used primarily for scientific problems); JOVIAL (for military applications); COBOL; SIMSCRIPT; LISP; PL/I; CPL, and others. To give an indication of the varying styles of the languages, three samples are given: a simple program (to find the mathematical function e^x) is written in CPL, in ALGOL and in FORTRAN [*see illustration on page 113*].

The advent of programming languages of this kind some nine years ago vastly enriched the art of programming. Before then a program containing 5,000 instructions was considered quite large, and only the most experienced or foolhardy programmers would attempt one. Today an individual can tackle programs about 10 times larger; a team by cooperative effort may produce a program still larger by a factor of five to 10.

By far the most important of the new programming languages was FORTRAN; until recently, it has been estimated, more than 90 percent of all scientific and engineering programs were written in it. In the past few years it has gradually become clear that current programming languages are by no means perfect and that the great success of FORTRAN was due to its relative merits rather than its absolute ones. Other programming languages such as ALGOL and LISP have shown that there are easier ways to do at least some things on computers.

To get back to our checkers program: I have written the complete program (except for certain details, including the input and output arrangements) in an informal and somewhat extended version of CPL (which stands for "Combined Programming Language"). The program in symbolic form, together with a list of the terms used and their definitions, is shown on the preceding page. The program is not by any means in final form; it has not been run on a machine and therefore, in accordance with the views expressed below, probably still contains some errors. Interested readers may like to look for them.

In the early days of computer programming—say 15 years ago—mathematicians used to think that by taking sufficient care they would be able to write programs that were correct. Greatly to their surprise and chagrin, they found that this was not the case and that with rare exceptions the programs as written contained numerous errors. The process of discovering, locating and correcting these errors proved to be one of major difficulty, often taking considerably longer than writing the program in the first place and using a great deal of machine time.

Although programming techniques have improved immensely since the early days, the process of finding and correcting errors in programs—known, graphically if inelegantly, as "debugging"—still remains a most difficult, confused and unsatisfactory operation. The chief impact of this state of affairs is psychological. Although we are all happy to pay lip service to the adage that to err is human, most of us like to make a small private reservation about our own performance on special occasions when we really try. It is somewhat deflating to be shown publicly and incontrovertibly by a machine that even when we do try, we in fact make just as many mistakes as other people. If your pride cannot recover from this blow, you will never make a programmer.

It is not, in fact, in the nature of human beings to be perfectly accurate, and it is unrealistic to believe they ever will be. The only reasonable way to get a program right is to assume that it will at first contain errors and take steps to discover these and correct them. This attitude is quite familiar to anyone who has been in contact with the planning of any large-scale operation, but it is com-

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Creating New Directions in Electronics pletely strange to most people who have not.

The trouble, I think, is that so many educational processes put a high premium on getting the correct answer the first time. If you give the wrong answer to an examination question, you lose your mark and that is the end of the matter. If you make a mistake in writing your program—or, indeed, in many other situations in life outside a classroom—it is by no means a catastrophe; you do, however, have to find your error and put it right. Maybe it would be better if more academic teaching adopted this attitude also.

It is when we first come to grips with a computer and actually try to run a program, either to test it or to obtain some useful results, that we really begin to get frustrated. In spite of the much vaunted speed of the machine itself, it is normally several hours and sometimes several days before one can actually get back the answer to even the shortest program. When this delay is added to the fact that computers and their programming languages and compilers are often most unhelpful, so that the only information you receive at the end of a day's wait may be that your program is still wrong, it is easy to understand why so many people get the impression that using a computer is more a matter of fighting the machine and the system than it is one of cooperation.

The reason for this curious situation is the desire to keep the computer, which is a very expensive machine, fully occupied for as much of the time as possible. The organization outside the computer, which frequently employs quite a large human operating staff, accounts for almost all the "turn-around time" and a fair proportion of the frustration. The introduction of time-sharing systems should remove this source of frustration, at the cost of greatly increasing the size and complexity of the operating programs [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128].

A large part of the work involved in actually getting a program running can be done by the computer itself. Operations such as translating the programming language into detailed machine code, allocating storage space inside the computer, keeping records to assist in the diagnosis of program errors, organizing the scheduling and accounting for a sequence of short jobs from various users and the like are precisely the kind of high-grade routine clerical work a computer can handle, and it is therefore only rational to expect the machine to do it.

The programs to make the machine carry out these operations are of the greatest importance. Most users of the computer will have far more contact with them than they do with the computer itself, and for this reason the operating programs are known as the software of the system (as opposed to the computer itself, which is known as the hardware). In actuality the performance of a system is as much dependent on its software as on its hardware, and the planning and writing of software systems is rapidly becoming a major problem for computer manufacturers. The entire set of these programs, known as the software package, can easily cost the machine manufacturer as much to produce and debug as the machine itself. As a result there is strong pressure not to change either the programming language or the operating system, in spite of the fact that in many respects they are seriously inadequate.

Why is the road from the conception of a program to its execution by the machine so long and tiresome? Why are the operating systems today—the software—so costly and unsatisfactory? Are we perhaps reaching the limit of human ability to write complicated programs, and is the present software crisis really the result of attempting the humanly impossible? Anyone who deals with the large computer systems today knows how close the whole thing is to collapsing under the weight of its own complexity.

There is no doubt that with the current techniques we have nearly reached our limit in programming. Could we not, however, improve the techniques? The checkers example we have considered in this article gives a strong hint that a simplified approach and improvement of the programming language would make things a great deal easier. If a suitable programming language existed, it should clearly be possible to write the entire checkers program in the way outlined above and leave nearly all the remaining stages to be performed by the computer. As a matter of fact, that can almost be done now, and it would probably not be too difficult to construct a language in which it was possible.

The only reasonable way to set up a large and complicated program is to use a hierarchical method. Since there is a limit to the size and complexity of a problem we can hold in our head at one time, it appears that the best way to extend our capability is to treat relatively large and complex operations as single

units and combine these units hierarchically. The present programming languages all pay at least lip service to this idea, but many do not allow for a genuine and unlimited hierarchy—only for two or three levels of operation (such as "local" and "global") the programmer has to consider simultaneously. Those languages that do allow a truly hierarchical treatment of a problem have only a limited ability to deal with representations.

The present-day computer is itself a stumbling block to the use of programs that are written hierarchically (or recursively). Because the computers are unsuitable for this kind of organization, the running of such a program is much slower than it is for a program written and coded in the conventional way. I am convinced, however, that the advantages of this kind of programming will far outweigh any increase of machine time that may be required. The advantages are so great that I believe the hierarchical method will eventually be adopted universally. After all, the chief purpose of any machine is to save human beings trouble; therefore we should not be unduly alarmed about giving the computer more of man's work. In addition, there is good reason to expect that it will be possible to design computers that will deal much more naturally and efficiently with deeply hierarchical programs. These machines will probably be slightly more complex than present ones, but the difference in cost will be well worthwhile.

I have left to the end what seems to me to be the most difficult, but also the most interesting and potentially rewarding, problem concerning programming languages. This is to lay a firm mathematical foundation for the construction of hierarchical systems of programs and to develop a calculus for manipulating them.

The difficulty arises basically from the fact that programming presents us with certain new questions that are not present, or at least not important, in any other branch of mathematics. The mathematical problem has two aspects. The first is how to deal explicitly and in a detailed way with complicated structures (involving representations of data) when not only the structure as a whole but also its component parts must be given names and have values assigned to them. The second aspect of the difficulty is that the use of imperatives (or commands) in programming introduces variables, and mathematics in general does not recognize the existence of vari-

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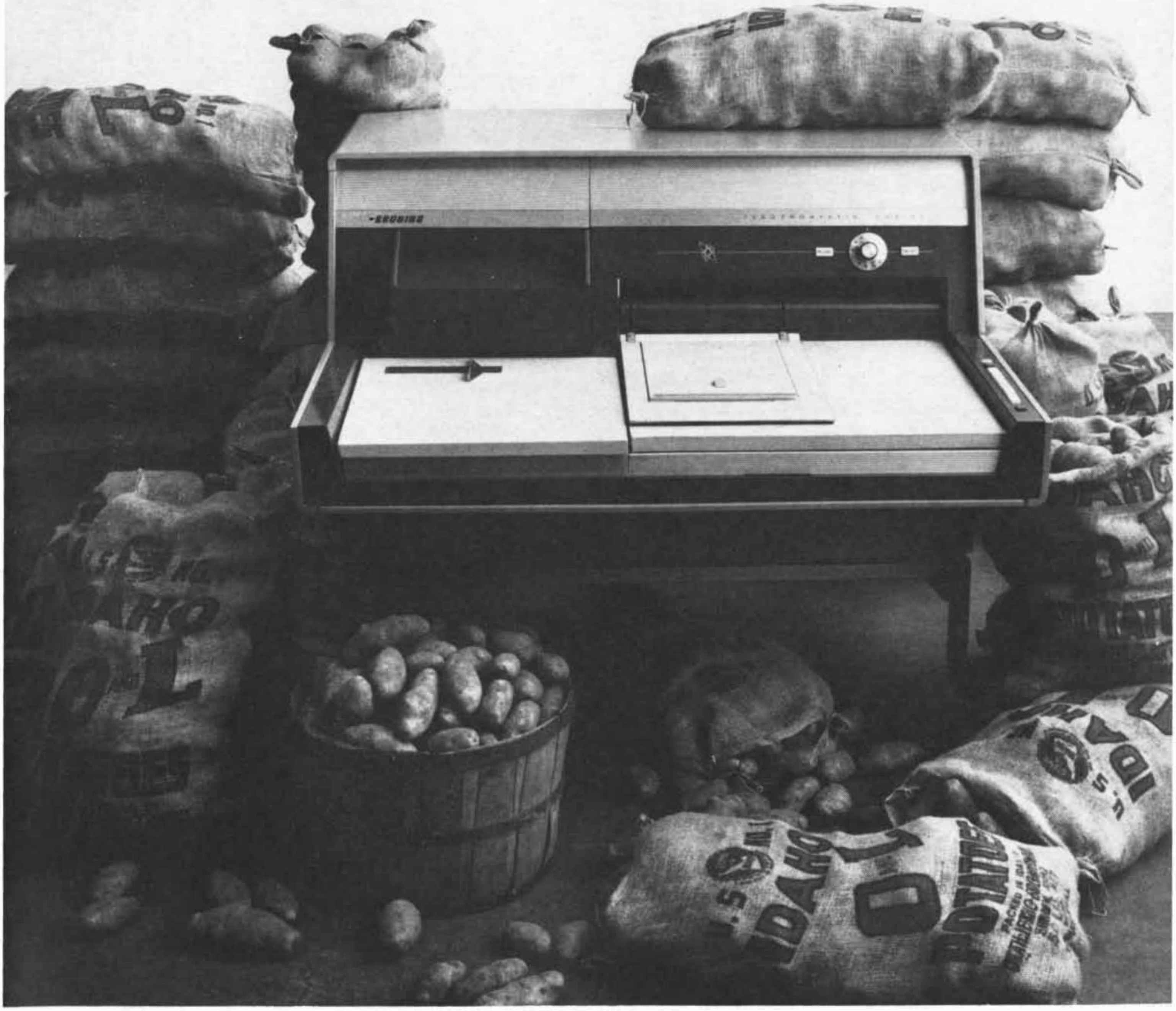

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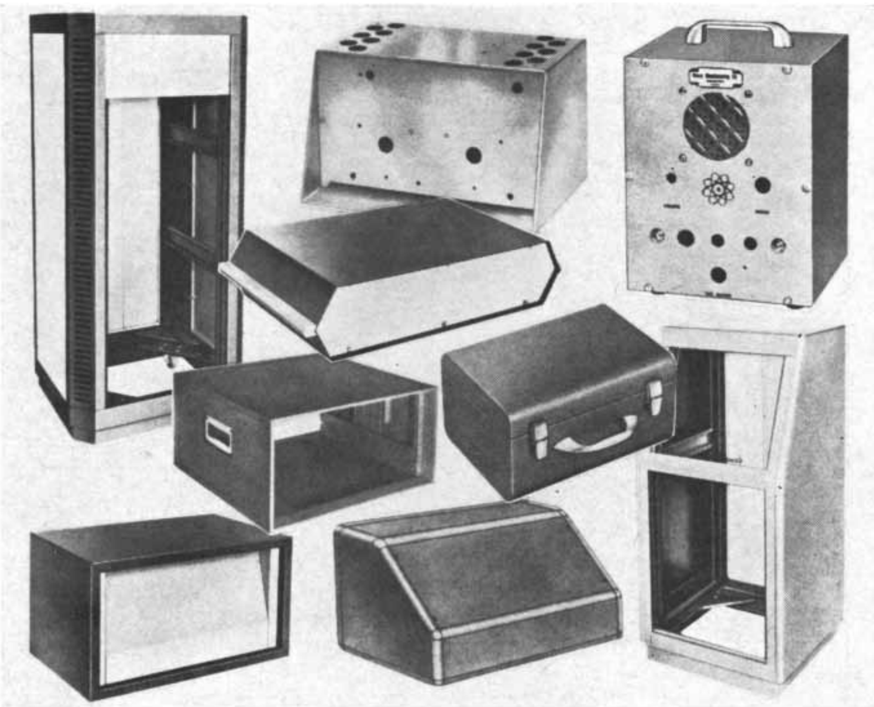


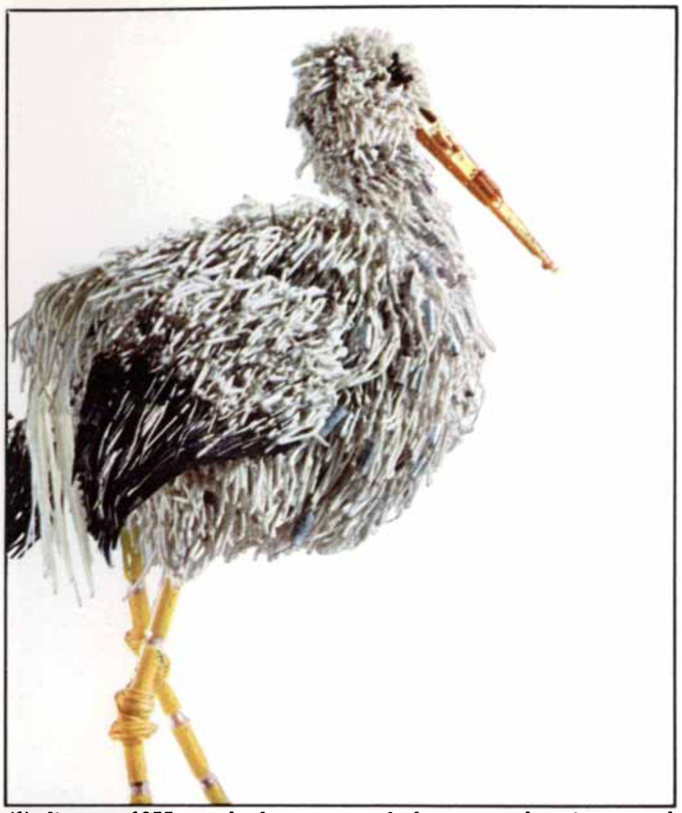
ables in this sense, that is, values varying over a period of time. In its traditional branches mathematics deals only with static situations. Even the calculus, which is concerned with the approaches of objects to a limit, deals with the subject in terms of a series of fixed values. In general the things mathematicians call variables are either constants whose values are not yet known or nonexistent quantities (such as "nobody") that are introduced for purposes of logical syntax. In programming, on the other hand, we deal with time-varying variables by the very nature of the process; a program is essentially a schedule of changes.

An experienced programmer reading this article will have been struck by the fact that in the formulation of the checkers program I have used no commands, and in particular by the fact that the program contains no assignment statements (statements assigning values to names or objects). The reason for this is that we know how to combine recursively defined functions into hierarchical structures only in the absence of assignment statements. There is still no satisfactory way of doing the same thing if they are included.

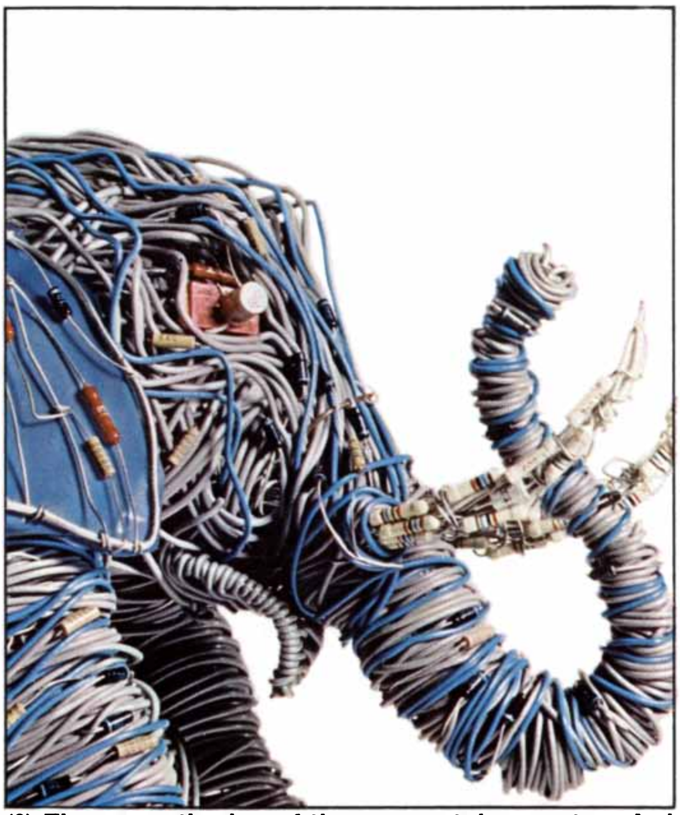
Investigation of the mathematical problems I have discussed has now begun. It is clear at the start that the field to be explored is almost entirely new, without established guidelines such as exist in most other areas of mathematical research. It is also evident that the first and most difficult task is to clarify what we mean, in a programming context, by terms such as "name" and "value." The chief trouble is that the introduction of assignments (changes of value with changes in circumstances) makes the meaning of the terms ambiguous from the standpoint of the way they are ordinarily used in mathematics, so that it seems probable we shall need to generate new concepts in order to get a firm grasp of the situation.

Much of the theoretical work now being done in the field of programming languages is concerned with language syntax. In essence this means the research is concerned not with *what* the language says but with *how* it says it. This approach seems to put almost insuperable barriers in the way of forming new concepts—at least as far as language *meaning* is concerned. I believe the way to progress for programmers lies along the path of research on meaning rather than syntax. It is primarily through the study of meaning that we shall develop the concepts required to build up hierarchical structures.

A Short Zoological History of a Very Busy Computer Firm

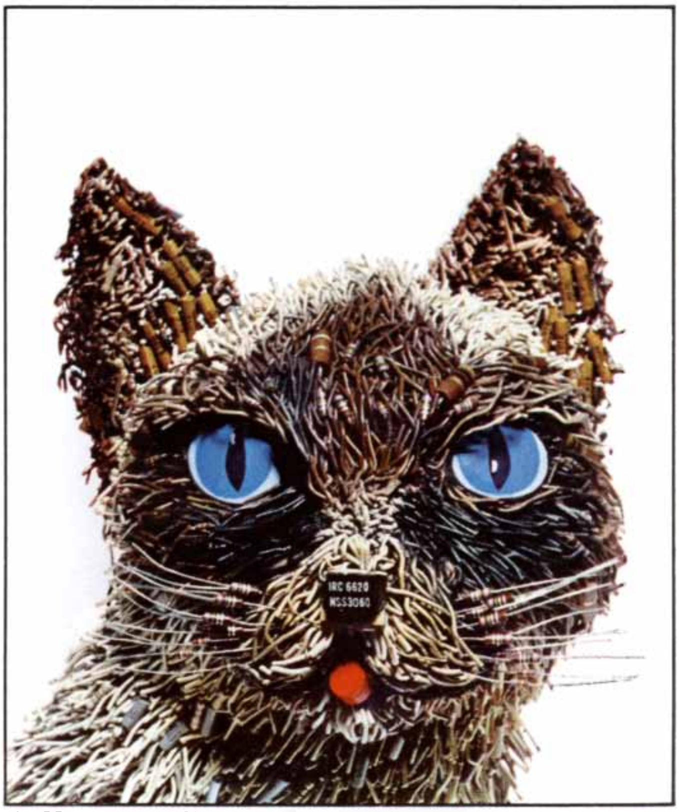


(1) It was 1955, and cigars were being passed out around Honeywell. The company that was to become Honeywell EDP was born. Honeywell was in the computer business. (Computer Control Company, which just recently joined the family, was already two years old.)



(2) Those were the days of the vacuum-tube monsters. And we had ours: the huge Datamatic 1000. (Several of these old timers are still turning out a full day's work for their demanding masters. We're using one of them ourselves to help design and build new computers.)

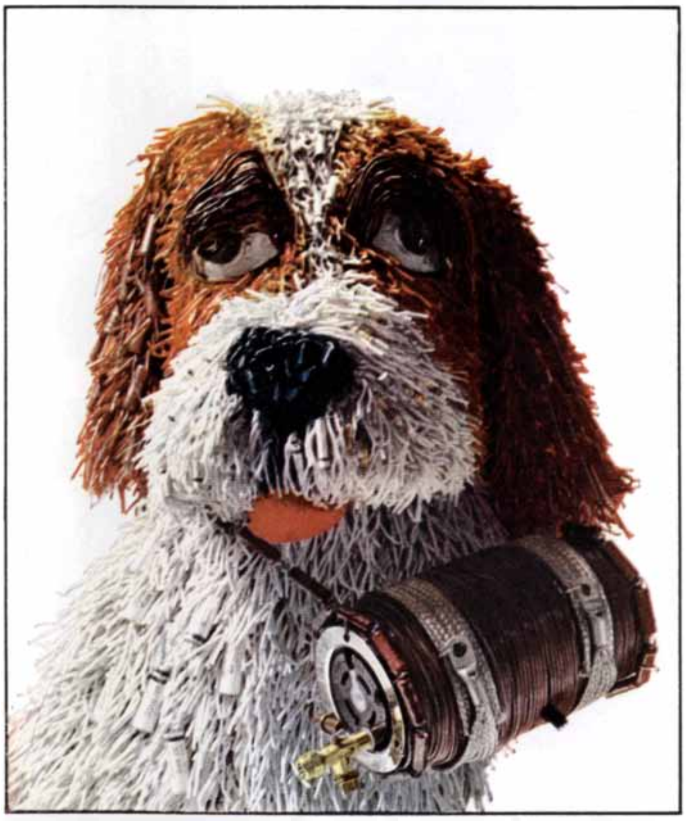
(5) Our next move was to breed a whole family of new generation computers. We took all the features that made the H-200 such a hopping success and built them into a small-to-high-powered line of six compatible models (120, 200, 1200, 2200, 4200, 8200). We call it Series 200.



(6) Meanwhile, Honeywell's process-control people weren't pussyfooting around, either. From our Pennsylvania facilities sprang new and versatile on-line computer systems to control such activities as the dispatch of electricity; manufacture of food, steel, textiles and chemicals; or processing and handling of materials.

(3) Then suddenly everybody was jumping to transistors. The second generation had arrived. And Honeywell hopped right to it with a great new computer, the H-800 (and then the 400, 1400, and 1800). One of many H-800 innovations was parallel processing, the ability to run as many as eight programs at the same time.

(4) We were moving well, but it was time to spurt. We pulled ahead of all the others with the first of the current new-generation computers. Our unique Liberator concept made it easy to switch from competitive systems to Honeywell. And we were off and running.



(7) And when Computer Control Company, Inc., a top dog in digital technology, joined the team, it expanded our integrated circuit know-how, added digital logic modules, core memories and magnetic test instruments to our product line. 3C computers (DDP-124, DDP-224, DDP-24, DDP-116 and more to come) are favorites in applications like flight simulation, physics research, radio astronomy, and freight-yard control.

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TIME-SHARING ON COMPUTERS

This technique, whereby a computer serves a large number of people at once, does more than save time and money. It sets up a dialogue between user and machine and allows communication among users

by R. M. Fano and F. J. Corbató

The history of the modern computer has been characterized by a series of quantum leaps in our view of the machine's possibilities. To mention only two of the crucial advances, the application of electronics, vastly increasing the computer's speed of operation, and later the invention of special languages, facilitating communication with the machine, each in its turn opened new vistas on the computer's potentialities. Within the past few years the technique called time-sharing has again stimulated the imagination. It has created an unexpected new order of uses for the computer.

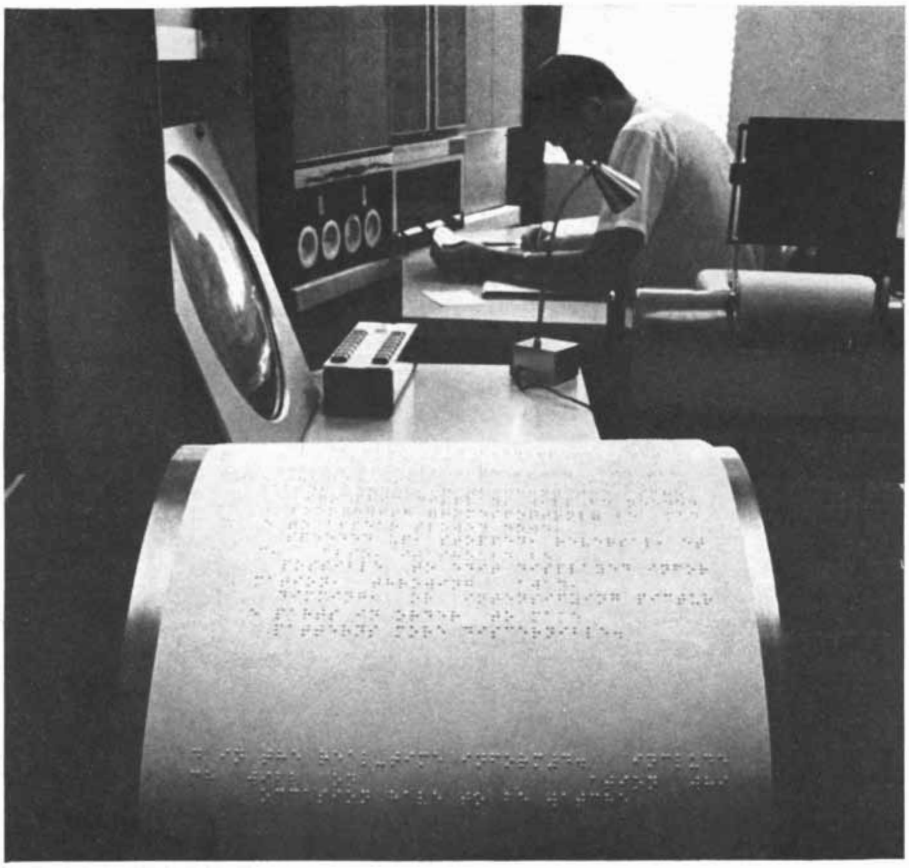
At first thought time-sharing seems simply a convenience: a means of allowing fuller use of the machine by more people and of saving time for the users. In practice, however, experiments with the technique have demonstrated a wide range of more interesting possibilities. It enables the user to conduct a continuous dialogue with the machine and in effect makes the computer his intellectual assistant. Further, the system makes it possible for the users to carry on a discourse with one another through the machine, drawing on its large store of knowledge and its computing speed as they do so. The time-sharing computer system can unite a group of investigators in a cooperative search for the solution to a common problem, or it can serve as a community pool of knowledge and skill on which anyone can draw according to his needs. Projecting the concept on a large scale, one can conceive of such a facility as an extraordinarily powerful library serving an entire community—in short, an intellectual public utility.

It was Christopher Strachey, the author of the article on system analysis and programming in this issue, who first proposed (in 1959) a time-sharing system. The large, expensive computing machines had become far removed from their users, both in time and in distance. An applicant in effect had to deliver his problem or program to a receptionist and then wait hours or sometimes days for an answer that might take the machine only seconds or even less time to produce. The computer, working on one program at a time, kept a queue of users waiting for their turn. If, as commonly happens, a submitted program contained a minor error that invalidated the results, the user often had to wait several hours for resubmission of his corrected program. Strachey suggested that the rapidity of a computer's operations made all this waiting unnecessary. By segregating the central processing operations from the time-consuming interactions with the human programmers, the computer could in effect work on a number of programs simultaneously. Giving only a few seconds or often less than a second at a time to each program or task, the machine could deal with many users at once, as if each had the machine to himself. The execution of various programs would be interspersed without their interfering with one another and without detectable delays in the responses to the individual users.

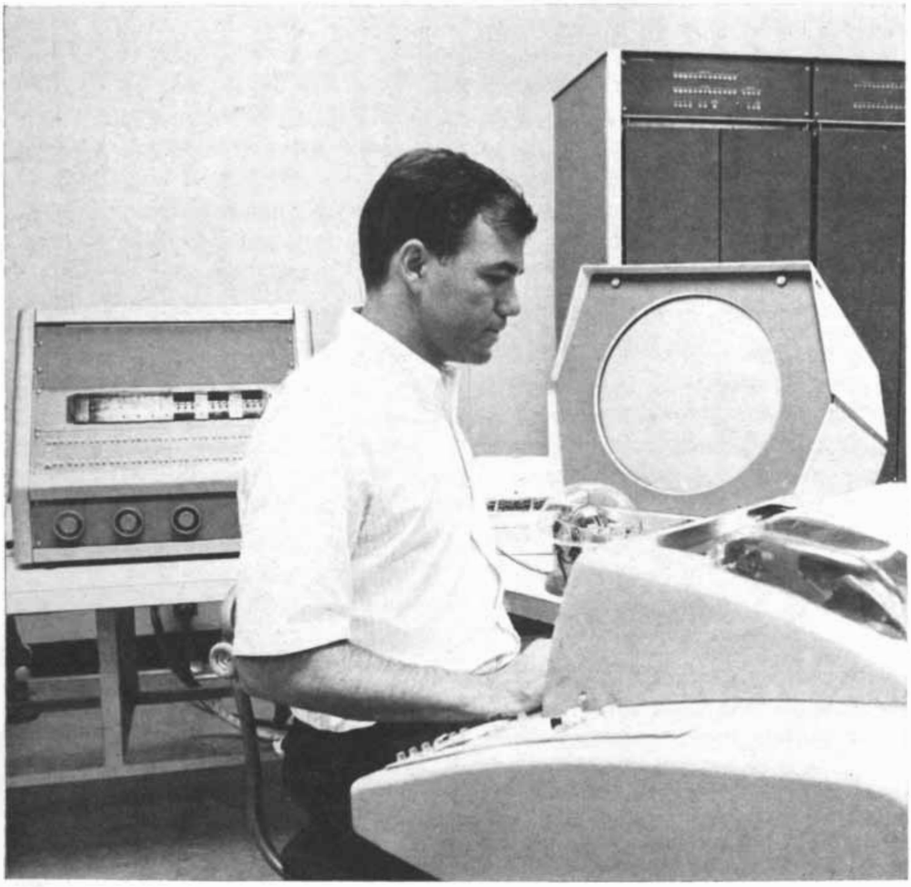
The Computation Center at the Massachusetts Institute of Technology quickly took up Strachey's suggestion. By November, 1961, the center had implemented and demonstrated a first model of the Compatible Time-Sharing System, using an International Business Machines Corporation 709 computer. Two years later an improved version of this system was operating on two IBM 7094 computers, one at the Computation Center and another at M.I.T.'s Project MAC (an acronym that has been variously translated as standing for multiple-access computer, machine-aided cognition or man and computer). By that time three other time-sharing systems had been developed: at Bolt, Beranek and Newman, Inc., at M.I.T.'s Research Laboratory of Electronics and at the System Development Corporation, and several more have since been developed at other research institutions.

Inherent in the time-sharing concept is a system of multiple direct connections to the computer from many points, near and far. At M.I.T. there are now 160 such stations, each with a teletypewriter that enables the user to enter his message directly in the computer's input and to receive its replies. These stations are installed in various offices and laboratories on the M.I.T. campus and in

PROJECT MAC time-sharing system at the Massachusetts Institute of Technology has 160 terminals on the M.I.T. campus and nearby and is also available from distant terminals. As many as 30 terminals can be connected at one time, with each user carrying on a direct and in effect uninterrupted dialogue with the computer. The terminals, 30 of which are shown on the opposite page, are for the most part simple teletypewriters such as the IBM 1050 (*6*) and Teletype models 33 (*19*), 35 (*5*) or 37 (*10*). Some are in offices, some in large "pool" rooms, some in laboratories and a few in private homes (*1*). In addition to students and staff members doing their own research, the users shown here include secretaries preparing papers for publication (*13*), authors Fano (*8*) and Corbató (*24*) and a psychiatrist at the Massachusetts General Hospital (*18*). More elaborate terminals are shown on the next page.



SPECIALIZED TERMINAL of Project MAC has a small computer, the Digital Equipment Corporation's PDP-8, operating a braille printer (*foreground*) for a blind staff member.



ANOTHER TERMINAL is the "Kluge" display system developed by M.I.T.'s Electronic Systems Laboratory. It has a control unit, display screen, light pen and other equipment.

the homes of some of the research staff and faculty members. Through a private branch exchange each station can by dialing reach either the Project MAC computer or the one in the Computation Center. Moreover, the Project MAC installation is connected to the teletype networks of the Bell System and Western Union, so that access to the computer can be had from thousands of terminals in the U.S. and abroad. Thus the two computer systems at M.I.T. are being used daily by a large and varied community, with each of them providing prompt response for up to 30 simultaneous users. The systems constitute an operating model of the information utility that John McCarthy, the author of the introduction to this issue, described in 1961 in an address picturing computer services of the future.

For professional programmers the time-sharing system has come to mean a great deal more than mere ease of access to the computer. Provided with the opportunity to run a program in continuous dialogue with the machine, editing, "debugging" and modifying the program as they proceed, they have gained immeasurably in the ability to experiment. They can readily investigate new programming techniques and new approaches to problems. The bolder exercise of the imagination encouraged by the new system has resulted not only in more flexibility in attacks on problems but also in the undertaking of important new researches in a variety of areas.

Let us now examine the operation of a time-sharing system. Taking the M.I.T. Compatible Time-Sharing System (CTSS) as our model, we shall first present a sample of what it can do, using a program dialogue for illustration, and then describe the anatomy and machinery of the system in schematic terms.

To begin with, the system contains a large store of information—supervisory and utility programs, language-translating facilities, a library of subroutines and so on—adding up to nearly a million computer words, which is equivalent to about 2,000 book pages crowded with nonredundant symbols. The basic content of the system is a set of some 100 programs, each of which is called into play by a specific command issued through a teletypewriter. They have to do with the ordinary operations of the system and involve communication, control of its various processes, the use and translation of computer languages and so forth. In addition to these 100 basic programs the system contains a great variety of special programs that are also available for general use. To all this "public" information there is added a large amount of material consisting of individual users' private files of programs and information.

Consider, then, an illustrative dialogue between a user and the computer [*see illustrations on pages 132 through 134*]. The user introduces himself by giving the command "login" and stating the project he wants to work on and his name. The machine responds by printing the time of day (to the hour, minute and tenth of a minute), and the user is now called on to give his password. This has been found to be a highly important requirement: it is necessary to guard the privacy of each personal set of files and protect the information and programs from accidental or malicious alteration by someone else. (Experience has shown that some people are unable to resist the temptation to commit mischievous vandalism of that kind.) The printer is disconnected while the password is being typed so that no record of it appears on the print-out.

If the given password does not check with the person's name and problem number, or if he has exhausted his monthly allowance of time on the computer, or if the machine is already being used to capacity (the maximum number of people who can use the computer at one time in our present system is 30), the machine prints a message stating that access is not available. If access can be granted, the user is allowed to proceed with further commands. Before beginning his work he may ask for an accounting of the amount of time and storage space he has used up from his allotted quotas (as one illustration shows). After this housekeeping query the user goes to work on his problem. Here, in our simple illustration, he

COMPUTER ROOM at M.I.T. houses the IBM 7094 central processing unit, memories and other central units of the Project MAC system. Disk and drum files are visible in left background, central processor in right background, tape-storage units at right.

```
login t193 fano
W 2237.7
Password
 T0193  2859 LOGGED IN  05/27/66     2237.8 FROM 20000N

 CTSS BEING USED IS     MAC5A4
 LAST LOGOUT WAS  05/27/66    2237.0
R 2.833+.900



ttpeek
W 2238.2

 5/27  2238.2 TUSED =   .1

SHIFT       MINUTES
      ALLOTTED   USED
 1       60       3.8
 2       20       1.0
 3        5       0.
 4       30        .3

      STORAGE
DEVICE   QUOTA   USED
DISK       100      4

R 1.950+.350



ed mad
W 2238.8
INPUT:
start read and print data
      an"mean = (x+y)/2.
      gmean = (x?   gmean = sqrt.(x*y)
      print results g"amean, gmen
      transfer to start
      end of program

EDIT:
top
print 10

START       READ AND PRINT DATA
            AMEAN = (X+Y)/2.
            GMEAN = SQRT.(X*Y)
            PRINT RESULTS AMEAN, GMEN
            TRANSFER TO START
            END OF PROGRAM
END OF FILE REACHED BY:
PRINT 10
file demo
R 3.983+2.550



mad demo
W 2242.9
 THE FOLLOWING NAMES HAVE OCCURRED ONLY ONCE IN THIS PROGRAM.
 COMPILATION WILL CONTINUE.
      GMEAN
      GMEN
LENGTH 00066.  TV SIZE 00005.  ENTRY 00017
R 1.750+.650

ed demo mad
W 2243.3
EDIT:
locate gmen
change /gmen/gmean/
print
            PRINT RESULTS AMEAN, GMEAN
top
change /amean/armean/ 10
END OF FILE REACHED BY:
CHANGE /AMEAN/ARMEAN/ 10
file
R 3.800+1.300

mad demo
W 2244.7
LENGTH 00063   TV SIZE 00005.  ENTRY 00016
R 1.466+.416

loadgo demo
W 2245.0
EXECUTION.
x = 123.456, y = 234.567 *
X = 123.456, Y = 234.567 *

          ARMEAN =    179.011499,          GMEAN =    170.172569
 QUIT,
R 5.483+1.283

save demo
W 2245.9
R .866+.283
```

RUNNING DIALOGUE between man and machine is demonstrated by a computer print-out. The user (*lowercase letters*) announces himself; the computer (*uppercase*) gives the time. The user gives his password (which, to preserve privacy, is not printed) and the machine logs him in and reports the number of seconds used by the central processor in the exchange. In response to the command "ttpeek" the machine summarizes Fano's time and memory-space account. With "ed mad" Fano writes and edits a program in MAD language for computing the arithmetic and geometric means of any two numbers. (The symbols " and ? erase the preceding character or all the preceding characters in the line respectively.) The program is filed under the name "demo." The machine queries a typing error ("GMEN" for "GMEAN"), which is corrected, and "AMEAN" is changed to "ARMEAN." The program is translated and executed. After a test computation the execution is interrupted. The computer acknowledges the interruption ("QUIT") and is instructed to "save" the program.

writes, translates and executes a program to compute the arithmetic mean and the geometric mean of two given numbers. A command signified by "ed" (for "editing") brings into play a subsystem in the computer that accepts various editing instructions, so that the user can call on it to write his program in a particular language (here it is the language called Michigan Algorithmic Decoder, or MAD) and make alterations, corrections or other manipulations of the program text as directed. Typing errors have been introduced deliberately in our example to illustrate some of these editing functions. The corrections are carried out through a dialogue between the user and the computer. Finally the program is translated and tested on a pair of numbers. The user presses an "interrupt" button at that point to end the computation and the computer prints out "QUIT" in acknowledgment. The user then gives the command "save demo," which instructs the machine to file the program in what becomes a new private file named "demo saved." This file is stored permanently in the system's mass memory.

The owner can command the system to print out the list of files in his file directory by giving the instruction "listf." He may also give a command authorizing the system to allow other named users access to one of his files, and conversely may gain access to other private or public files he is permitted to use. Although a person given access to someone else's file is not usually allowed to change that file, he can copy its contents, file the information separately under his own name and then modify the data or program for his own use. This technique is employed by a second person to use the program for computing the arithmetic and geometric means of a pair of numbers [*see bottom illustration on opposite page*]. Another convenient feature of the time-sharing system that is illustrated allows the depositing of messages from one user to another in the computer. On logging into the computer a user may be informed by the machine that there is a message in his "mail box," and the computer will then print the message on command.

To illustrate the editing capabilities of the system we have added a sample print-out of a paper delivered at a conference, together with the commands that enabled the computer to present it in the desired typographical form. The system includes a special facility for editing English text, and this facility has been used in the preparation of technical reports and other publications.

Not the least useful feature of the Compatible Time-Sharing System is the fact that it carries its own set of instructions to its users. Stored in its mass memory is the manual describing the system; this is indexed by a table of contents listing the various services and sections in the reverse chronological order of their addition to the system; that is, the latest are listed first. Thus a user can readily check at any time to see whether or not his copy of the manual is up to date and can then obtain a print-out of any new or modified sections.

To explain the workings of the system we have focused on the dialogue carried on between the user and the computer through the medium of printed commands and responses. The Project MAC system also includes two display stations with facilities for light-pen drawing on a cathode ray tube and for viewing the projection of continuously rotating three-dimensional objects. This equipment has been used by Cyrus Levinthal for studying the structure of biological molecules [see "Molecular Model-building by Computer," by Cyrus Levinthal; SCIENTIFIC AMERICAN, June.]

Of the anatomy and internal operations of the M.I.T. time-sharing system we can only give a schematic outline. It employs a very large and complex installation, built around an IBM 7094 computer and containing in addition a number of special units [*see illustration on page 135*].

The heart of the system is a complex of programs called "the supervisor." It coordinates the operation of the various units, allocates the time and services of the computer to users and controls their access to the system. The allocation function includes scheduling of users' requests, transferring control of the central processor from one user to another, moving programs in and out of the core memory and managing the users' private files. Obviously the time allowance for each program-run must be closely regulated. If a program runs too long without interruption, other users will be kept waiting unduly; on the other hand, if the execution of a program is interrupted many times, the repeated movement of the program in and out of the core memory will entail a waste of time. We have adopted a time-allowance scheme based on task priorities that in

```
listf
W 2246.0

     6 FILES    24 RECORDS
 NAME1  NAME2 MOD NOREC   USED
   DEMO  SAVED 000    18 05/27/66
(MOVIE TABLE) 001     1
   DEMO    BSS 000     1
   DEMO    MAD 000     1
PERMIT   FILE 120     1
  FJCC (MEMO) 000     3 05/19/66

    28 LINKS
 NAME1  NAME2 MOD PROBN. PROGN. LNAME1 LNAME2
 BASIS  SAVED 104  T0173     44
CIRKIT  SAVED 000  T0113 CMFL04
CONVOL  SAVED 104  T0173     44
 CONVT    BSS 104
  DATA  SAVED 104
DATTOC (MEMO) 104  T0254    3212
DOCTOR  SAVED 144  T0109    2531
  GETF  SAVED 104  T0173     44
 GRPS1   DGET 144  T0263    32
- QUIT,
R 1.666+.300



permit demo saved 4 t100 385
W 2248.4
R .816+.266

edl permit mills
W 2248.9
 FILE PERMIT MILLS NOT FOUND.
Input
t 19?t193 2859 per "mits file demo saved to t100 385 mills

Edit
top

print 2

T193 2859 PERMITS FILE DEMO SAVED TO T100 385 MILLS
file
R 4.400+1.500

mail permit mills t100 385
W 2254.7
R 1.366+.433
```

DIRECTORY of Fano's personal files is printed out in response to the command "listf." It includes three files associated with the new "DEMO" program as well as "LINKS" to public and private files that Fano may use. Fano goes on to give permission for another user named Mills to use the new means-computing program and sends a message to Mills telling him so.

```
 login t100 mills
W 2255.4
Password
 YOU HAVE     MAIL   BOX
 T0100   385 LOGGED IN  05/27/66     2255.7 FROM 20000A

 CTSS BEING USED IS     MAC5A4
 LAST LOGOUT WAS  05/27/66    1555.3
R 2.766+.716

print mail box
W 2256.2

  MAIL    BOX      05/27  2256.3

FROM   T0193  2859 05/27 2254.7
T193 2859 PERMITS FILE DEMO SAVED TO T100 385 MILLS
R .683+.516

link demo saved t193 2859
W 2257.9
R 1.266+.433

resume demo
W 2258.0
x = 345.678, y = 456.789 *
X = 345.678, Y = 456.789 *


          ARMEAN =    401.233498,          GMEAN =    397.368725
 QUIT,
R .133+1.450

logout
W 2259.2
 T0100   385 LOGGED OUT 05/27/66    2259.3 FROM 20000A
 TOTAL TIME USED=     .1 MIN.
```

USER MILLS, logging in, is told that there is a message in his "MAIL BOX." After reading the message he asks that a link be established to the "demo saved" program that has been permitted to him. When this has been done, he asks the computer to "resume" the program, applying it to two new numbers he provides. The machine does so and prints the answers.

```
resume who
W 2300.6

MAC5A4 STARTED AT 1451.1 05/27

  BACKGROUND USED  142.6.      PERCENTAGE =     0
 17  USERS AT  2300.9 05/27

LINE   USER      NAME  GRP UNIT   TUSED TIMEON
 1 C0056 99995 FIBMON  0 (FIB)      .1 2217.9
 2 C0056 99999 DAEMON  0 DAEMON  37.6 1451.2
 4 T0269  8048 ENNING  3 200007   2.0 2115.9
 5 T0143   799    LIU  1 20000+   7.8 1923.7
 6. T0281  3712 MAURER  1 20000+   8.8 1805.0
 7 T0113  4619  WYLIE -1 600040    .8 2250.0
 8 T0193  2859   FANO  2 20000N    .7 2237.8
 9 T0269  8031 SSANNA  3 20000.   3.6 2044.0
10 T0234  1122 GARMAN  1 700168   1.4 2211.7
11 T0186  4288 INTOSH 15 20000+   5.9 2128.2
12 T0109  2531 ENBAUM  1 20000W   4.5 2125.9
13 T0145  3667 HITMAN  1 600038   1.8 2218.7
14 T0312  3047 NICHEL  1 20000Y   1.9 2222.5
15 T0335  4655 ULIANO -1 20000+    .1 2258.2
16 T0113  3556 EPHUIS  1 200000   3.3 2139.8
17 T0186  3187 MORRIS -1 100035    .4 2223.9
19 T0234  3308 WIDRIG  1 100001   1.4 2227.8

R 1.850+2.133
```

THROUGH A LINK to the system's public file, Fano asks for and receives a print-out of the system's current users, the time they logged in and the amount of time they have used.

```
typset fjcc
W 2303.3
Edit
top
print  20

.page
.header SOCIAL IMPLICATIONS OF ACCESSIBLE COMPUTING
.center
SOME THOUGHTS ABOUT THE SOCIAL
.center
IMPLICATIONS OF ACCESSIBLE COMPUTING
.space
.center
by
.space
.center
E. E. David, Jr.
.center
Bell Telephone Laboratories
.space
.center
R. M. Fano
.center
Massachusetts Institute of Technology
file
R 5.733+.916



runoff fjcc
W 2305.8
Load paper, hit return



                SOME THOUGHTS ABOUT THE SOCIAL
              IMPLICATIONS OF ACCESSIBLE COMPUTING

                             by

                       E. E. David, Jr.
                  Bell Telephone Laboratories

                         R. M. Fano
             Massachusetts Institute of Technology


                          ABSTRACT

The pattern of our  business  and  private  lives  has  been
shaped by many important technological developments such  as
automobiles, electric power and telephones.   The  influence
of these products of technology was felt  when  they  became
available to a large segment of the population.  We are  now
at that stage with computers.

As   with   previous   products   of   technology,  accessible
computing will undoubtedly benefit  society  but  will  also
face us  with  new  problems  and  new  frustrations.   The
underlying issues are very complex and they  deserve  prompt
and thoughtful consideration on the part of all of us.



logout
W 2307.9
 T0193  2859 LOGGED OUT 05/27/66    2308.0 FROM 20000N
 TOTAL TIME USED=     .9 MIN.
```

EDITING CAPABILITY of the system is illustrated by the machine's reproduction of the beginning of an article. The command "typset" calls up the program for editing and printing the text. Commands prefaced by a period, such as "center" and "space," are instructions on format. The command "runoff" produces a print-out in the specified format. Logging out, Fano learns that demonstration, which lasted 30.3 minutes, used .9 minute of computer time.

turn are determined initially by the amount of information that must be transferred into the core memory. The smaller the amount of information, the higher the initial priority the task is given. The time allowance is at least two seconds and doubles with each level of decreasing priority. If a task is not completed in its allotted time—or if a higher-priority task is waiting—it is interrupted and enough of the program moved out to a storage drum to make room in the core memory for the next task awaiting the processor's services. If the allotted time has been exhausted, the task's priority is lowered and a correspondingly doubled allocation of time is made. The interrupted task is then continued when its turn comes up again.

The user need not remain in communication with the system while his program is being run. He may write a program in collaboration with the machine, test it and, after he is satisfied that it is correct, instruct the internal supervisor to run the program for him and store the results in a file from which he can retrieve them later at his convenience. This arrangement, called FIB (for "Foreground-initiated Background"), is designed particularly for programs involving lengthy computations that do not require human intervention. The present system also allows, in effect, for the concurrent running of programs on a "batch" basis (that is, not time-sharing), but this facility is now largely superseded by FIB.

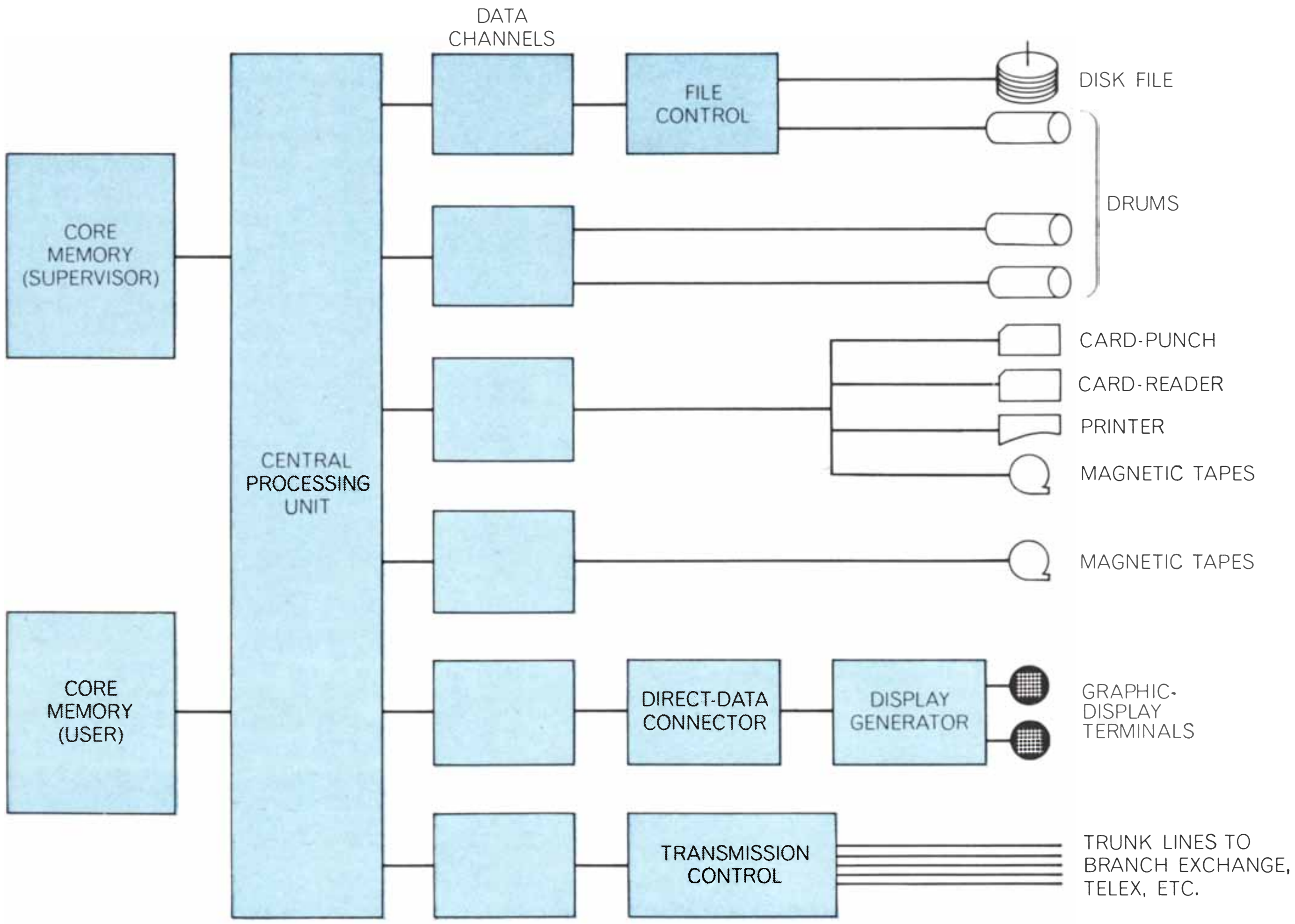
This, then, in sketchy outline, is the compatible time-sharing system we have been working with so far at M.I.T. It is only a precursor, of course, of systems that will be developed in the future. What improvements or advances are needed to create an installation that will serve a large community as a general public utility?

One obvious necessity is that the system provide continuous and reliable service. A public utility must be available to the community 24 hours a day and seven days a week without interruption. It should not shut down for accidents, repairs, maintenance, modifications or additions to the system. This implies, among other things, that the system should not depend completely on any one unit. It suggests that every part of the system should consist of a pool of functionally identical units (memories, processors and so on) that can operate independently and can be used interchangeably or simultaneously at all times [*see upper illustration on page*

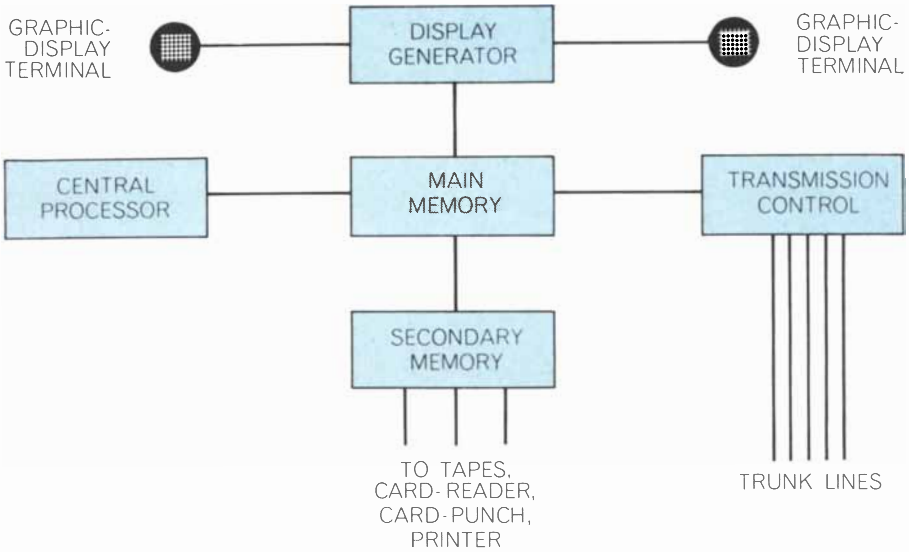
138]. In such a system any unit could be taken out of service for repair or maintenance during a period when the system load was low, and the supervisor would distribute the load among the remaining units. It would also be a simple matter to add units, without interrupting service, as the use of the system grew. Moreover, the availability of duplicate units would simplify the problem of queuing and the allocation of time and space to users.

A second need is more efficient use of the computer's time. In the Compatible Time-Sharing System, as in most conventional batch-processing systems, the central processor is idle for about 40 percent of the time because it must wait while programs and data are being transferred in and out of the core memory and while necessary information is being fetched from or written into the users' files. One way to reduce the processor's idle time would be to have at all times in the core memory several executable programs (instead of only one), so that as soon as the processor finishes a task or transmission of more data is required, it would find another task available. The computer art now presents a technique for producing this desirable situation without having to waste too much core memory to store entire programs waiting to be executed. A program can be divided into pages, each containing, say, only 1,024 words, and the core memory can be divided into logical blocks of the same size. Pages are transferred into core memory only when needed, if at all, so that tasks can be initiated with minimal use of precious memory space.

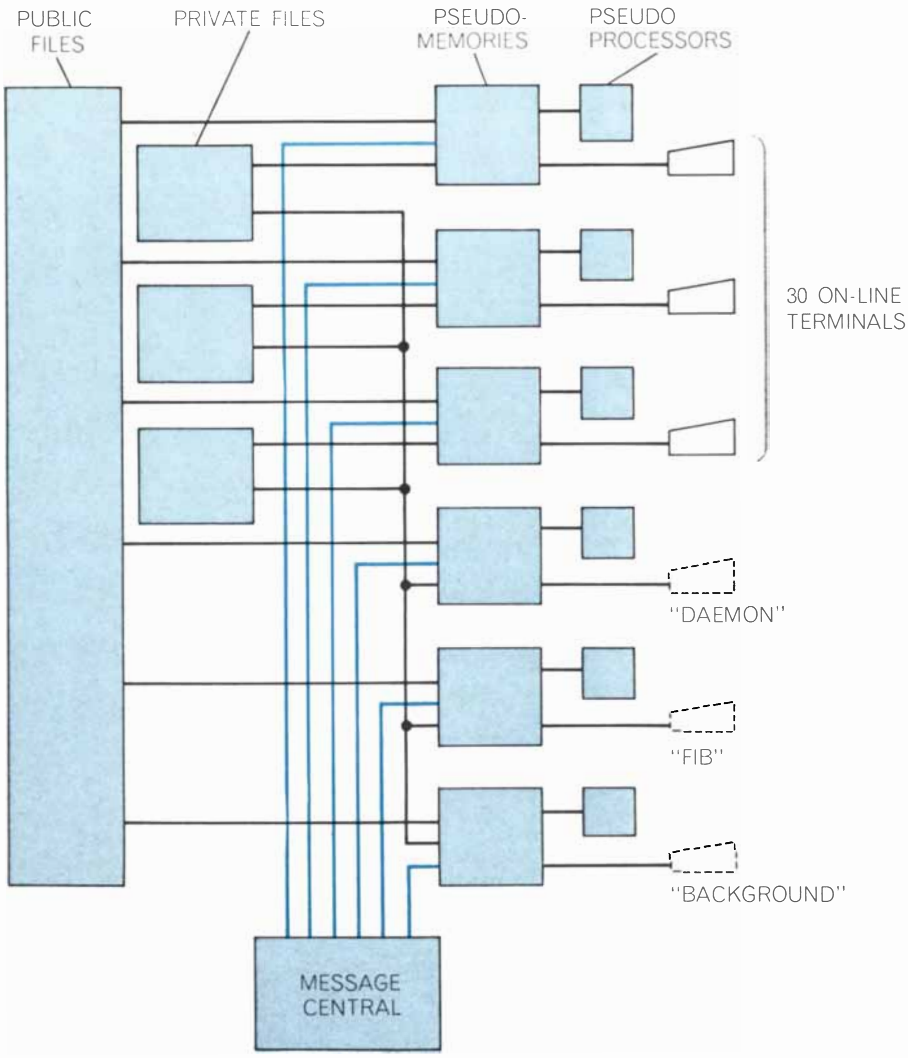
Another new technique, called program segmentation, has been advocated by Jack B. Dennis of M.I.T. to increase the ease and flexibility with which subprograms may be linked to form large programs. The process followed by a computer in executing a large program is similar to that followed by the reader of an article that refers to a section of another article that in turn refers to a chapter of a book, and so on. The traditional technique for linking subprograms is equivalent to having a clerk in the library make copies of all articles and books to be read, assemble them into a single volume, and translate all references into references to specific page numbers of the volume. This technique has the disadvantage that popular subprograms have to be copied and stored many times as parts of different programs. Moreover, programs, unlike articles and books, are often changed and new subprograms have to be incorporated. This is particularly true in a time-sharing system. With the technique of program segmentation the segments, or subprograms, retain their individual identity at all times. They are retrieved from mass storage only when the computer finds a reference to them during the execution of some other segment. Speed of retrieval, and particularly speed of access to individual words of a segment after the segment has been retrieved, is essential. For this purpose



PRINCIPAL ELEMENTS of the M.I.T. time-sharing computer installation are shown in a simplified schematic diagram. One of the two core memories is occupied by the supervisor program, which runs the system; the other is available to users. Files are moved into the core memory as needed from the disk and drum memories. The transmission control is actually a special-purpose computer.



SUPERVISOR has the effect of reducing the equipment layout diagrammed on the preceding page to the functional arrangement illustrated here. The main (core) memory, rather than the central processing unit, is in effect the central unit with which other units communicate; the various mass storage devices are in effect a single secondary memory.



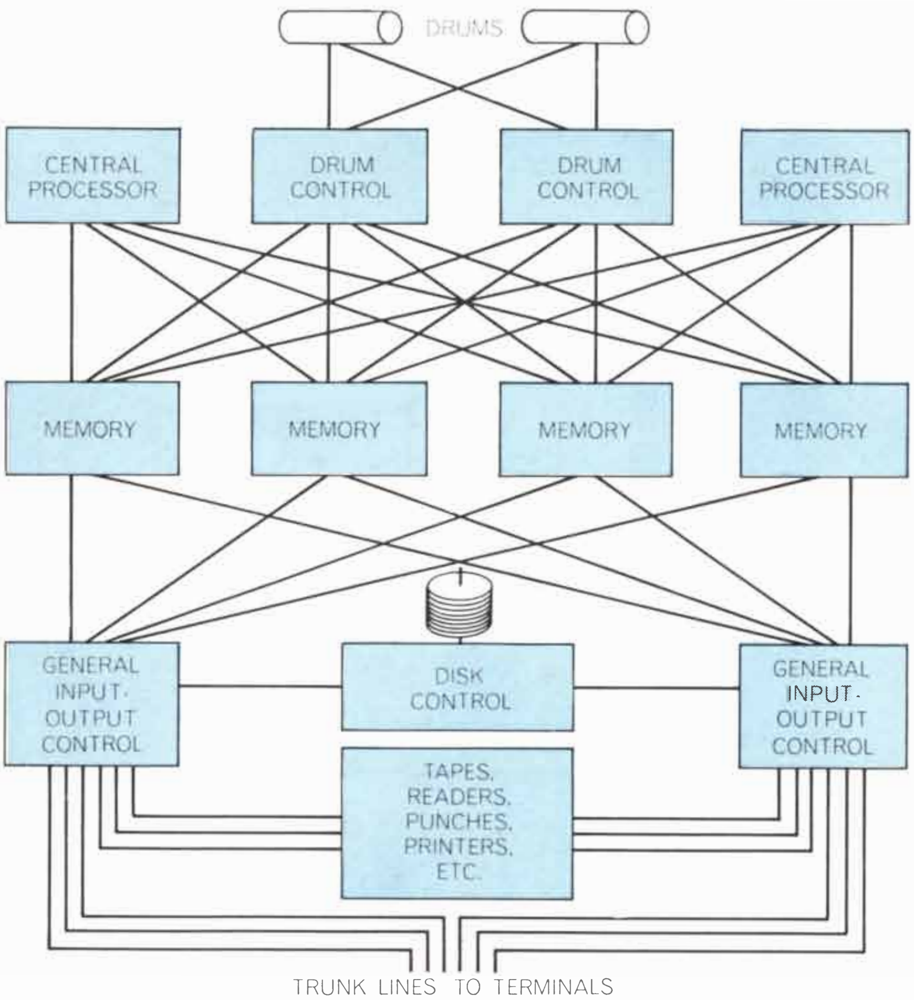
"USER'S VIEW" of the system is quite different. Each of the 30 on-line users has available, for all practical purposes, his own processor and memory. Each memory has in effect a capacity of 32,768 words and has access to public files as well as the user's own files. Messages can be exchanged through the message central. Three special pseudo-processors are available to the supervisor. "Daemon" copies files on tape. "FIB" takes over and executes programs for users who do not need to wait for lengthy answers. "Background" operates as a conventional computer, batch-processing large tasks fed into the central computer.

the computer must include special equipment features, and appropriate directories of all segments must be maintained. The position of the computer is then analogous to that of a user of an ideal automatic library who finds in his reading a reference to some article or book. He gives the name or names identifying the article or book and the page or line number in which he is interested, and the desired text is quickly displayed for him so that his reading can continue without appreciable interruption. The technique of program segmentation appears to have many other advantages beyond those suggested here, and these are currently being explored in a number of research laboratories. Segmentation makes it possible for several central processors to combine in working on a program involving much computation and improves intercommunication within the system [*see lower illustration on page 138*]. Two new commercial computers, the General Electric Company's 645 and the IBM 360/67, include the special features needed for paging and for program segmentation.

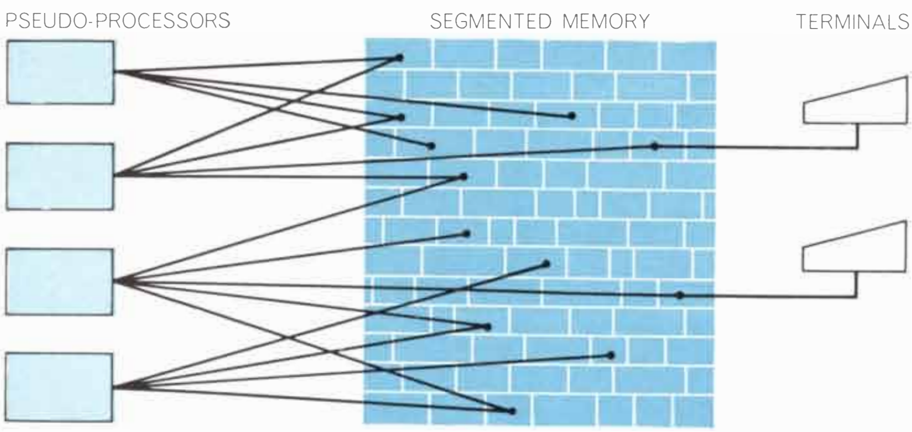
Finally, in this catalogue of improvements needed to develop time-sharing computers into general intellectual utilities we must mention a bottleneck for which a practicable solution is not yet in sight. The output devices still leave a great deal to be desired. The teletypewriter is a frustratingly slow means of communication—and it cannot draw a picture. The graphical display devices that are currently available are expensive and require elaborate communication facilities. Inasmuch as, from the standpoint of convenience and of economics, efficient communication between the time-sharing system and its users will become at least as important as the operation of the system itself, this problem presents a crucial challenge to designers.

Three years of experience with the Compatible Time-Sharing System at M.I.T. have been a revelation in many ways. In a sense the system and its users have developed like a growing organism. Most striking is the way the users have built on one another's work and become dependent on the machine. More than half of the commands now written into the system were developed by the users rather than by the professionals charged with programming and developing the system. The users have very generally chosen to link up with one another's private files and the public files. Whereas in conventional computer

installations one hardly ever makes use of a program developed by another user, because of the difficulty of exchanging programs and data, here the ease of exchange has encouraged investigators to design their programs with an eye to possible use by other people. They have acted essentially as if they were writing papers to be published in technical journals. Indeed, the analogy is not far-fetched: an editorial board representing the community of users acts as a referee to pass on all new commands that are to be introduced into the system and on all



PROPOSED DESIGN for a time-sharing computer would provide more dependability and flexibility than present systems. There would be several elements of each kind, so that no one unit would be critical. The main memories would be central physically as well as functionally. And the supervisor would assign each task to available units as required.



SEGMENTATION OF PROGRAMS adds to the flexibility of a time-sharing system. Each public and private file becomes an independent segment stored in the main memory, each with its own list of authorized users. There are no pseudo-memories, since each pseudo-processor can communicate with a number of segments, some shared with other processors.

information science in action:

How to use Western Union's nationwide computer network to find a better job

Now—for only $1 a month—you can rent time on a $500 million computer & communications network that matches openings to your requirements—even though you're not actively looking.

Until recently, locating a better job was often a matter of luck and timing. You might plod along for years without finding what you wanted—or stumble, by chance, on an opportunity that meant the difference between success and failure.

Now, through a new application of the computer, it is possible to eliminate this element of chance. You can learn about attractive openings *as they occur* through PICS—Personnel Information Communications System—a new nationwide service which uses computers to match qualified men with the jobs they want.

PICS was developed by five former IBM executives who helped create the world's first efficient system of matching men and jobs by computer. They recently organized INFORMATION SCIENCE INCORPORATED to help professional, technical and administrative people learn about openings which match their individual goals.

PICS uses Western Union's $500 million computer and communications network to match your resumé against detailed job descriptions flowing in from employers in 66 industries. PICS constantly job hunts for you, even when you're not actively looking.

Access to firms seeking someone like you

Once you are enrolled in PICS, you have automatic access to employers throughout the country who are searching for someone with just your particular combination of skills, experience and career objectives. PICS does not waste your time on positions which would not interest you.

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At the same time, the employer gets a copy of your confidential resumé, identified only by code and omitting your name and the name of your firm. He may contact you if he wishes—but he must do it through PICS, and you need not respond.

PICS is not an employment agency—and is not designed primarily for the unemployed. PICS' mission is to match your skills with every available job opportunity—no matter where, no matter when. You have no obligation to accept—or even consider—any position. *Should you accept, there is no placement fee.*

And even while you're not actively "looking," the PICS computers also compile quarterly salary analysis reports to show you exactly where you stand in your profession. With these reports, you can make comparisons with others by age group—by degree level—by professional skills classification.

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It takes just a few minutes to fill out the PICS enrollment form. In the process, you will be programming your complete skills profile for the PICS computers. You need never again risk missing a better job for which you qualify—either because you are not looking, or because you are looking at the wrong time. PICS will be looking *all* the time. And you will be eliminating the element of blind chance on which your future success now hinges.

Dale H. Learn, President of Information Science Incorporated, developed the concept of using computers to match skills with jobs, while he was Corporate Employment Manager for IBM. He is shown, at right, with Russell W. McFall, President of Western Union, whose $500 million computer and communications complex is the nerve center for this unique new nationwide service.

To enroll, mail coupon or call any of Western Union's 1600 offices today

The complete cost of PICS' service is $1 per month payable annually—regardless of how many jobs you consider. This nominal fee is possible because the major portion of PICS' operating expenses is underwritten by subscribing corporations. To enroll, send no money now. Just mail the coupon below, or dial "Operator" and ask for Western Union Operator 77—anywhere.

A Message to Corporation Presidents and their Top Executives

If you are concerned with sky-high recruiting costs, you are invited to investigate PICS' service to employers. The five principals of Information Science Incorporated have more practical experience in personnel data systems than any other group in the country today—and all this experience is behind the PIC System. For complete information on how PICS can slash your recruiting costs, dial "Operator" and ask for Western Union Operator 88—anywhere.

PICS—Dept. 405
Western Union Bldg., 60 Hudson St.
New York, N. Y. 10013

Please send the enrollment form to enter my career profile into the PICS computers. I understand that as quickly as I complete and return the form, my qualifications and preferences will be matched against nationwide job openings. The complete charge for this service, including quarterly salary analysis reports, is $1 per month payable annually, for which you will bill me later. However, I may return this material, unmarked within 10 days and owe nothing.

Name ____________________
Please print
Address ____________________
City __________ State __________ Zip Code __________
Occupation ____________________

information that is to be stored in the public files.

All in all, the mass memories of our machines are becoming more and more like a community library. The users are beginning to complain about the difficulty of finding out just what the library contains and locating the items that may be of interest to them. The facility actually goes beyond a library's usual services. It already has a rudimentary mechanism whereby one person can communicate with another through a program in real time, that is, while both are using the same program at the same time. There have been cases in which a member of the faculty, sitting at a teletypewriter at home, has worked with a student stationed at a terminal on the campus. It is easy now to envision the use of the system for education or for real-time collaboration between the members of a research team. And it does not take a long stretch of the imagination to envision an entire business organization making and executing all its major decisions with the aid of a time-shared computing system. In such a system the mass memory at all times would contain an up-to-date description of the state of the business.

Looking into the future, we can foresee that computer utilities are likely to play an increasingly large part in human affairs. Communities will design systems to perform various functions—intellectual, economic and social—and the systems in turn undoubtedly will have profound effects in shaping the patterns of human life. The coupling between such a utility and the community it serves is so strong that the community is actually a part of the system itself. Together the computer systems and the human users will create new services, new institutions, a new environment and new problems. It is already apparent that, because such a system binds the members of a community more closely together, many of the problems will be ethical ones. The current problem of wiretapping suggests the seriousness with which one must consider the security of a system that may hold in its mass memory detailed information on individuals and organizations. How will access to the utility be controlled? Who will regulate its use? To what ends will the system be devoted, and what safeguards can be devised to prevent its misuse? It is easy to see that the progress of this new technique will raise many social questions as well as technical ones.

RCA uses integrated circuits for moon travel...and

The moon is an alien place of "seas" without water and temperatures that dip to 250°F. below Zero. It can be reached only at shattering speeds that put the utmost stress on men and materials—and an absolute premium on reliability.

A formidable goal! But man *will* reach it—aided by RCA breakthroughs as significant to businessmen as they are to NASA and space travel.

Attitude controls built by RCA will help astronauts land on the moon's surface. Communications provided by RCA will link them to earth while they are there. And rendezvous radar built by RCA will help guide the astronauts in their Grumman-built Lunar Excursion Module to the Apollo command module on their return to earth.

All this calls for electronic skills of the highest

Fisheye lens view of N. Y. financial district

to make RCA business computers think faster

order. A call RCA has answered with the help of a remarkable invention—the integrated circuit.

These new circuits are small—just 1/400th of a square inch. Yet they do more work than conventional circuits—do it better, faster and with greater reliability.

What does this mean to the businessman? The heart of his RCA Spectra 70 computer is made up of circuits designed by RCA using the same micro-electronic skills required for moon travel. Their miniature size gives Spectra 70 its reliability, lower cost and amazing speed—so fast it is measured in billionths of a second. Spectra 70 is so versatile it talks to other computers. And so new it will *still* be new 5 years from now.

Come into the space age with RCA!

RCA

THE MOST TRUSTED NAME IN ELECTRONICS

THE TRANSMISSION OF COMPUTER DATA

Computer users are sending an increasing volume of digital data over the nation's electrical communication network. To transmit such data efficiently at high speed, the network is being modified

by John R. Pierce

Electrical communication is an adaptation of science and technology to the service of man. Computers too are servants of men. Computers can respond to and interact with man directly and immediately, as an automatic telephone switching system or an airline reservation system does. Or computers can do assigned chores and report back to man intermittently, as they do in inventory control or the making up of payrolls. In either case computers and the data they manufacture must somehow enter into the pattern of man's telecommunication.

Modern electrical communication had its origin in two apparently distinct inventions of the 19th century. One of these was the telegraph, which transmitted information by means of on-off signals that produced audible clicks. The receiving operator interpreted these clicks as letters and words of a message; he transcribed the message on a piece of paper or, in some instances, spoke it to an expectant recipient. The other early invention was the telephone, which transmitted, over a limited distance and faintly, the sound of the human voice.

I think we should add to these two inventions another two that are crucial to human uses of electrical communication. These are automatic telephone switching, which first brought man into large-scale contact with complicated logical machines, and the teletypewriter. These inventions enabled men who had no special training (such as the training of telegraph operators) to communicate electrically by dialing or by typing letters and numbers.

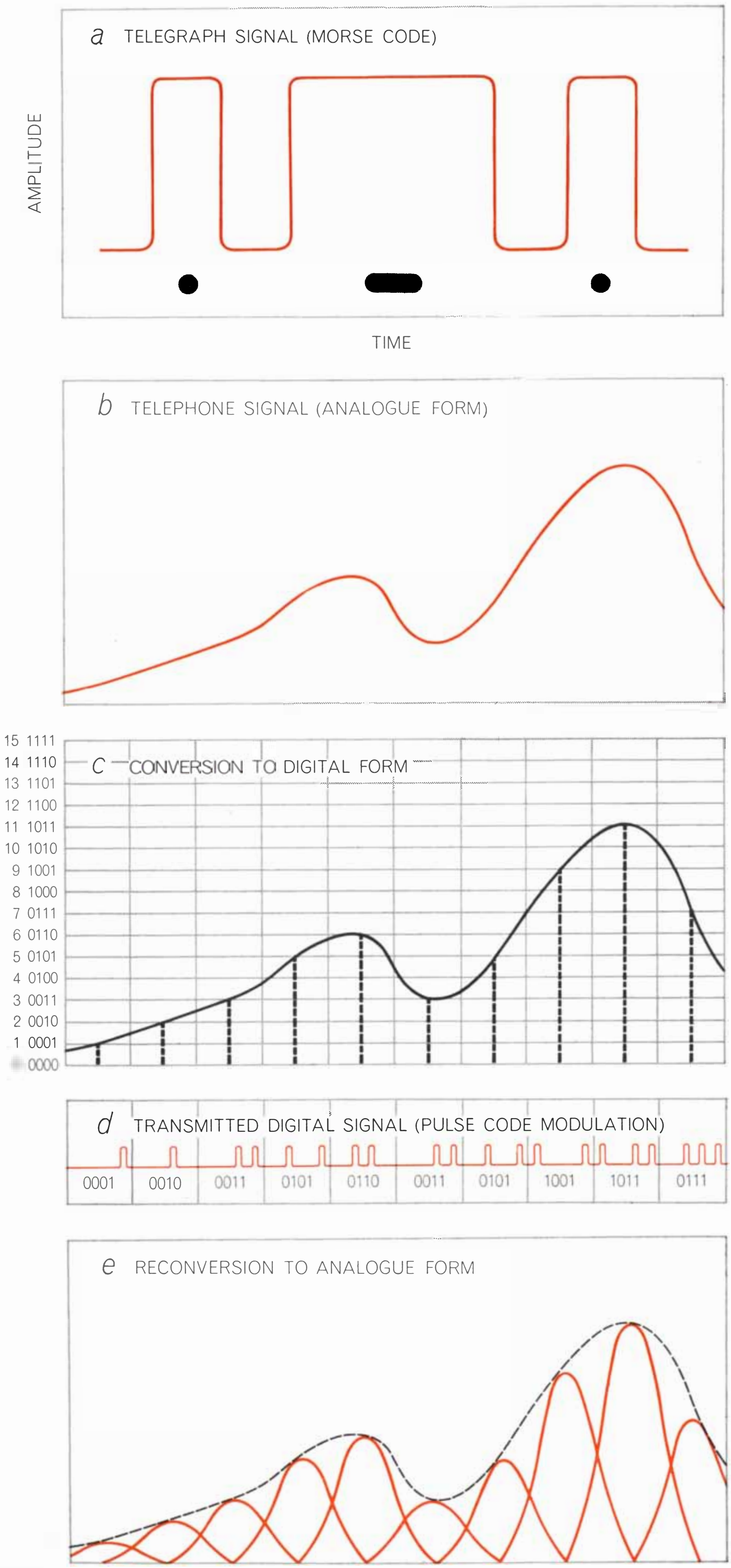
As we look back on the early telegraph and the early telephone, we see that they were as specialized as they were simply because of the limitations of the electrical art of their time. Even then, however, they were not entirely separate. Alexander Graham Bell discovered the telephone while working toward a harmonic telegraph, in which different signals would be simultaneously conveyed over the same pair of wires by electrical tones of different frequency. Still, for a long time there seemed to be some sort of intellectual or electrical distinction made between the kinds of signals employed for telegraphy and telephony.

This distinction gradually became less clear as telegraph signals were multiplexed—transmitted many at a time—over telephone lines in much the way Bell had envisioned in his work on the harmonic telegraph. Recently it has been shown that telephone signals can be transmitted by on-off impulses, using the method known as pulse-code modulation (PCM). In this method the varying amplitude of the telephone signal is sampled at frequent intervals and coded in numerical values, which are then converted into binary digits for transmission. At the receiving end of the line the operation is reversed [*see illustration on next page*].

Thus we have begun to see in electrical communication something of the universality of man's behavior and man's nervous system. We all use a mixture of reading and writing, listening and speaking and even gesturing in everyday life. In the human nervous system we find no distinction among the signals associated with different human senses and activities. The nerve impulses that travel from our fingers to our brain in the operation of the sense of touch, the nerve impulses that travel from the eyes to the brain in vision and the nerve impulses from the ear to the brain in hearing are all the same spikelike electrical signals. There is a uniform medium through which all our senses serve us. The same spikelike pulses control the muscles we use in writing and those we use in speaking. The human body employs a common communication system for both sensory and motor activities. The differences among such activities lie in the differences among the various sensors and effectors and in the functioning of the central nervous system.

In 1948, quite late in the evolution of communication technology, a logical framework was developed that is capable of describing, unifying, and quantifying the process of communication and control. Claude E. Shannon, then a young mathematician working for the Bell Telephone Laboratories, inquired: What are we really trying to do in the process of communication? This process, he said, begins with a source of information, which generates information at some particular rate. Information from the source is encoded and then transmitted over a communication channel. At the far end the message is decoded and a replica of the information at the source arrives at a destination.

MICROWAVE ANTENNAS (*opposite page*) **are clustered on the roof of the headquarters building of the long-lines department of the American Telephone and Telegraph Company in New York. The shedlike structures are microwave horns of two types: "delayed lens" and "cornucopia." Each radiates a microwave beam that can carry 600 one-way telephone channels. There are 10 such horns on the roof, not all of them visible. The roof also carries two dish reflectors used for temporary service and a variety of mobile-radio antennas.**

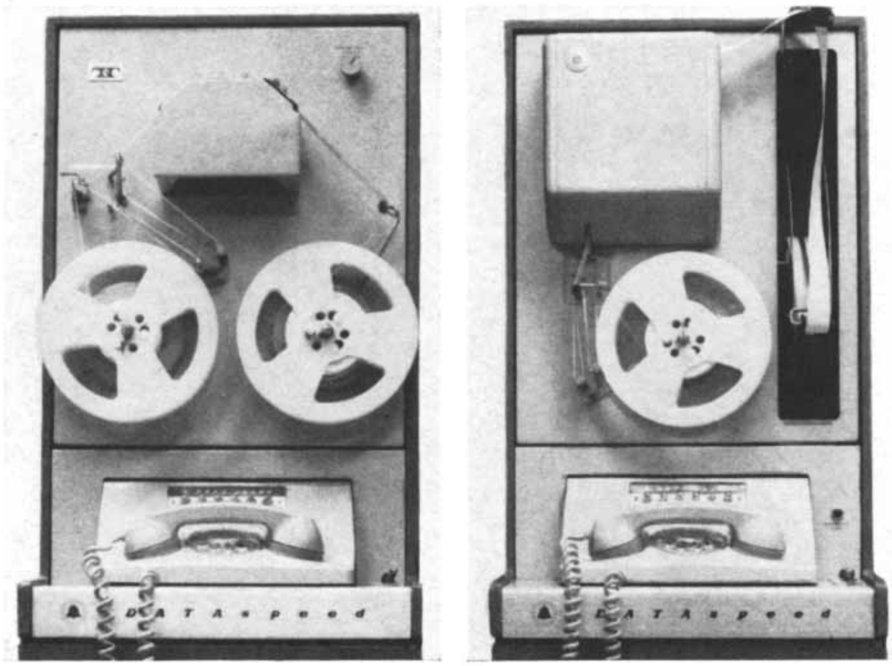


SIGNAL-CODING takes two basic forms: digital and analogue. A digital signal carries information in the form of pulses. Morse code (*a*) is an early example of a digital code in which the pulses vary in duration but not in amplitude. An analogue signal, such as a telephone signal (*b*), varies continuously in amplitude. An analogue signal can be converted to digital form by sampling its amplitude at regular intervals and assigning a numerical value to each sample (*c*). The numerical values of the samples can be converted to binary digits and transmitted as a sequence of 0's and 1's (*d*). This signaling method is called pulse-code modulation. At the receiving end of the line the binary numbers can be converted to smoothed pulses whose amplitude is proportional to the size of the number (*e*). The sum of these pulses regenerates the original analogue signal.

In order to talk sense about the process Shannon had to have a measure of the information rate of the source and a measure of the information capacity of the communication channel. He defined a universal measure and a universal unit of information: the bit (binary digit). A bit is the choice between plus or minus; it is the amount of information needed to remove the uncertainty between yes or no. It is a distinct choice, and hence it reminds us of the on-off character of the telegraph signal, but it is a universal choice. It applies equally well to the information rates and channel capacities of telegraph signals, voice signals, picture signals, and the signals that circulate through modern electronic digital computers and telephone switching systems. Through Shannon's work our conception of communication has come to fit the actual nature of electrical communication systems: circuits that can be used interchangeably for telegraph, voice and picture signals.

Shannon's equations demonstrated for the first time just how wasteful most communication channels are. He showed, for example, that a letter of English text contains only about one bit of information, if due allowance is made for letter frequencies in English words and the predictable constraints that exist in all written languages. In other words, with an efficient coding scheme one should be able to transmit ordinary English text with an expenditure of one bit per letter. Thus the information contained in a typical 300-word page of typewritten text is only some 1,800 bits. To transmit 300 words with ordinary data-transmission coding techniques, however, requires the expenditure of about 12,600 bits (a seven-bit code group for each letter). To transmit a page of text by facsimile requires about a million bits. In this case, of course, the entire page is transmitted as a picture, which is mostly white space. If the page were read aloud over a pulse-code-modulation telephone channel, one would need more than 11 million bits to transmit it. Finally, if the same page were transmitted by television for the time needed to read it aloud (say three minutes), more than 10 billion bits would be required. An obvious way to reduce the number of bits transmitted in this case would be to send the picture once, which would take only a thirtieth of a second, and then send a few bits of information containing the message: "Hold picture on screen for three minutes." Something analogous does happen, in fact, when a few lines of input to a computer result in many pages of print-out. In Shannon's sense there is no more information in the print-out than in the input that gave rise to it. Accordingly any message that can be generated at the terminal of a communication channel contains no information beyond the local input needed to produce it and therefore need not be transmitted.

This brief excursion into information theory is relevant because the users of computers are increasingly concerned about whether to install a computer at the site where computer problems exist or to transmit the problems to a computer at a remote site. By adopting the latter course one may be able to justify the installation of a large computer that can handle many inputs by the technique of time-sharing [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128]. Information theory makes it clear, however, that the "information" transmitted from the computer back to one of the time-sharing stations is not truly information. One can therefore afford to transmit it only as long as communication channels are cheaper than the computing machinery needed to generate it. The debate about when it is cheaper to transmit and when it is cheaper to compute has been agitating the computer industry for several years and will doubtless continue to do so as economic advantages swing one way and then another.



BELL SYSTEM'S "DATASPEED" service provides a convenient way to send digital data over a standard telephone channel. The transmission rate of Dataspeed is 1,050 words (about 70,000 bits) per minute. A Dataspeed sender is at the left, a receiver is at the right.

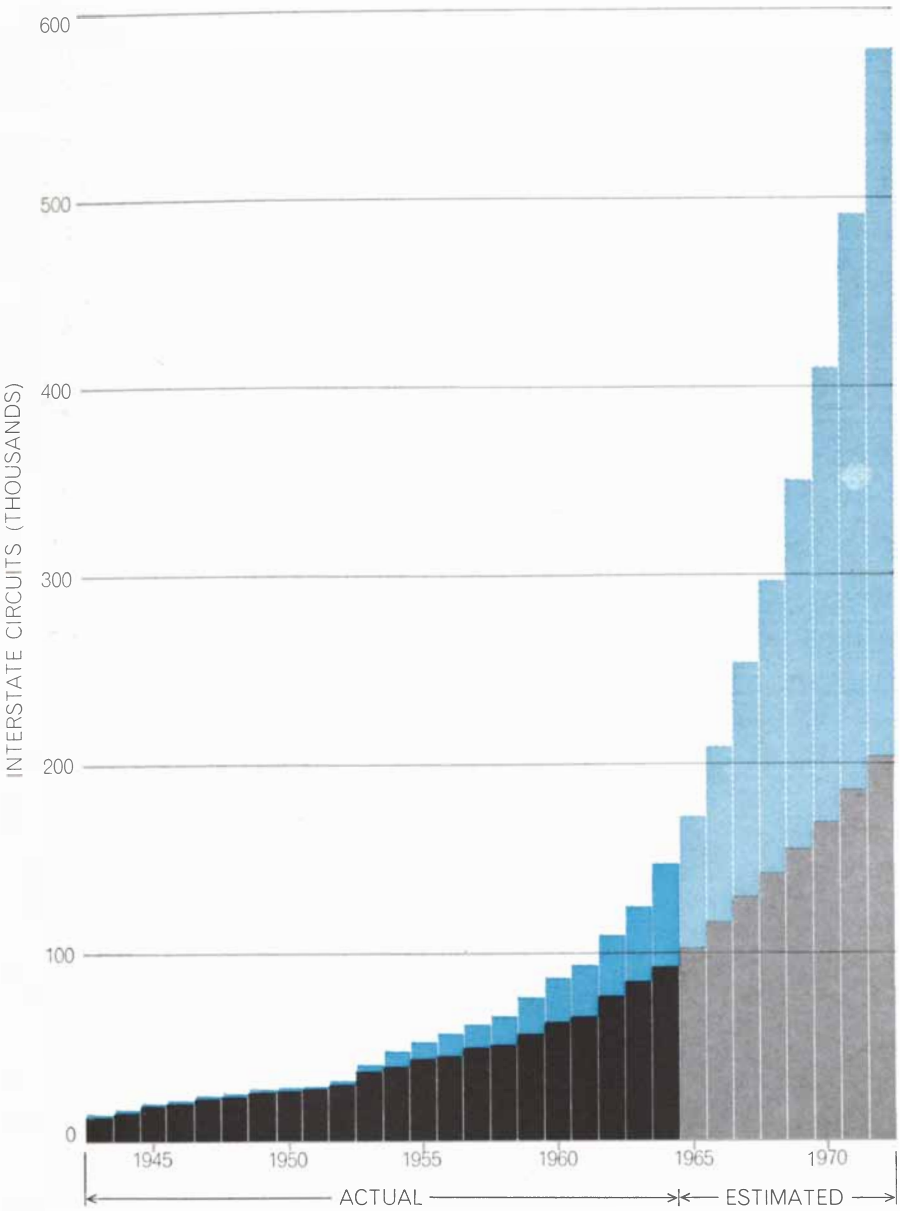
Still, it takes little imagination to foresee that in a world filled with computers as well as people the communication mix will be vastly different from what it is today. The trend is already foreshadowed in the use being made of the long-lines circuits of the Bell System [*see top illustration on next page*]. For the past 10 years "special service" circuits have been growing much faster than "message" circuits. The latter are used for ordinary switched telephone calls. The former are circuits, usually of the same nature, that are not used as part of the switched telephone plant but are used rather for the transmission of data, television, radio programs or the voice part of the television signal, facsimile, nonswitched private-line telephony or some other special service. The growth of special-service circuits reflects several areas of use: data transmission, closed-circuit television for educational and other purposes, and networks of circuits rented to large companies, sometimes for a highly mixed usage.

It is important to realize that, although the distinction between messages and special services is an important one, it is not a distinction between data and voice. Some of the most promising prospects of data transmission involve the telephone-message network. In Wilmington, Del., a person with an account at the Bank of Delaware can pay for a purchase at the nearby Stroms department stores even if he has left his wallet home and has no credit account at Stroms. After a purchase the salesclerk simply "dials" the number of the bank on a push-button ("Touch-Tone") telephone, enters a code that identifies the customer and then enters the amount of the purchase. Other banks that are pioneering in similar services include the Mercantile Trust Company N.A. of St. Louis, the Wells Fargo Bank of San Francisco and the Manufacturers Bank of Detroit.

The interaction of men and computers is not limited to "data" signals; it can involve voice or visual signals. Moreover, unlike the pulses produced by a telephone dial, the signals produced by push-button signaling resemble musical notes; they can be transmitted over any voice circuit and hence can be used to interrogate remote computers. How can the computer answer? In a system used by the Bankers Trust Company the computer responds over the line by a recorded voice.

We should also realize that in an up-to-date computer center much of the output may be graphs, diagrams and drawings rather than tabular print-out. The most efficient means for transmitting graphical material is to transmit the coded directions that would ordinarily be fed to the output device that makes the drawing. This means that a graphical output device with a considerable logical capability—a small computer in itself—must be used at the receiving end. In some cases this may prove impractical, and less efficient television or facsimile transmission may then be employed.

Similarly, computers can make use of



LONG-LINES CIRCUITS of the Bell System are increasing steeply. The black portion of each bar represents circuits used for conventional telephone messages. The portion in color represents equivalent voice circuits used for special services, such as facsimile, television and data of various kinds. Such circuits are expected to exceed message circuits next year.

TRANSMISSION SYSTEM	BITS PER SECOND	ONE-WAY TELEPHONE CHANNELS
PAIR OF WIRES (ONE WAY)	6×10^6	96
SINGLE COAXIAL CHANNEL (ONE WAY)	30×10^7	~5,000
COAXIAL CABLE (10 CHANNELS EACH WAY)	60×10^8	~100,000
WAVE GUIDE (TWO-WAY SYSTEM)	120×10^8	~200,000

CHANNEL CAPACITIES of four transmission systems capable of carrying either voice signals or data are shown here. In a coaxial cable only nine channels are ordinarily in use each way; the 10th is held as a spare. Wave guides are pipes, usually about two inches in diameter, that can carry broad-band microwave signals with small transmission losses.

graphical inputs. Again the efficient mode of transmission is to have a small computer to encode the input at the transmitting end, but again facsimile or even television might find a place putting graphical material into computers.

In the more distant future it may be possible to control computers, including telephone switching systems, by the human voice. Progress is being made in the automatic identification of speakers by voice, as a substitute for a handwritten signature, and this could play an important part in banking and other credit transactions.

The prospect before us, then, is a large growth in the use of all kinds of special signals in communicating with computers as well as with human beings. The flexible and universal nature of electrical communication will continue to make it possible for communication to grow freely and flexibly in meeting needs that have been and will continue to be less than completely predictable.

If we were to start afresh in building a universally adaptable communication network, there are persuasive arguments that it should transmit digital signals exclusively. Voice and other signals can now be converted economically to and from digital form at telephone offices. Digital signals could then be used in terminal equipment and throughout the switching apparatus. Such primitive signals are unspecialized, and can be used easily for any form of communication. About 64,000 binary pulses a second will provide a telephone circuit and about 64 million suffice for commercial television.

In the days of the vacuum tube such a digital network would have been uneconomical, but the transistor has made digital transmission practical, and the impending microelectronic revolution will steadily lower the cost of both digital transmission and digital processing, including digital switching.

Using today's technology, we could construct apparatus that would economically:

Transmit pulses over a single pair of wires at rates up to six million bits per second.

Transmit pulses through a coaxial channel at rates up to 300 million bits per second (a total capacity of three billion bits per second each way through a 20-unit coaxial cable).

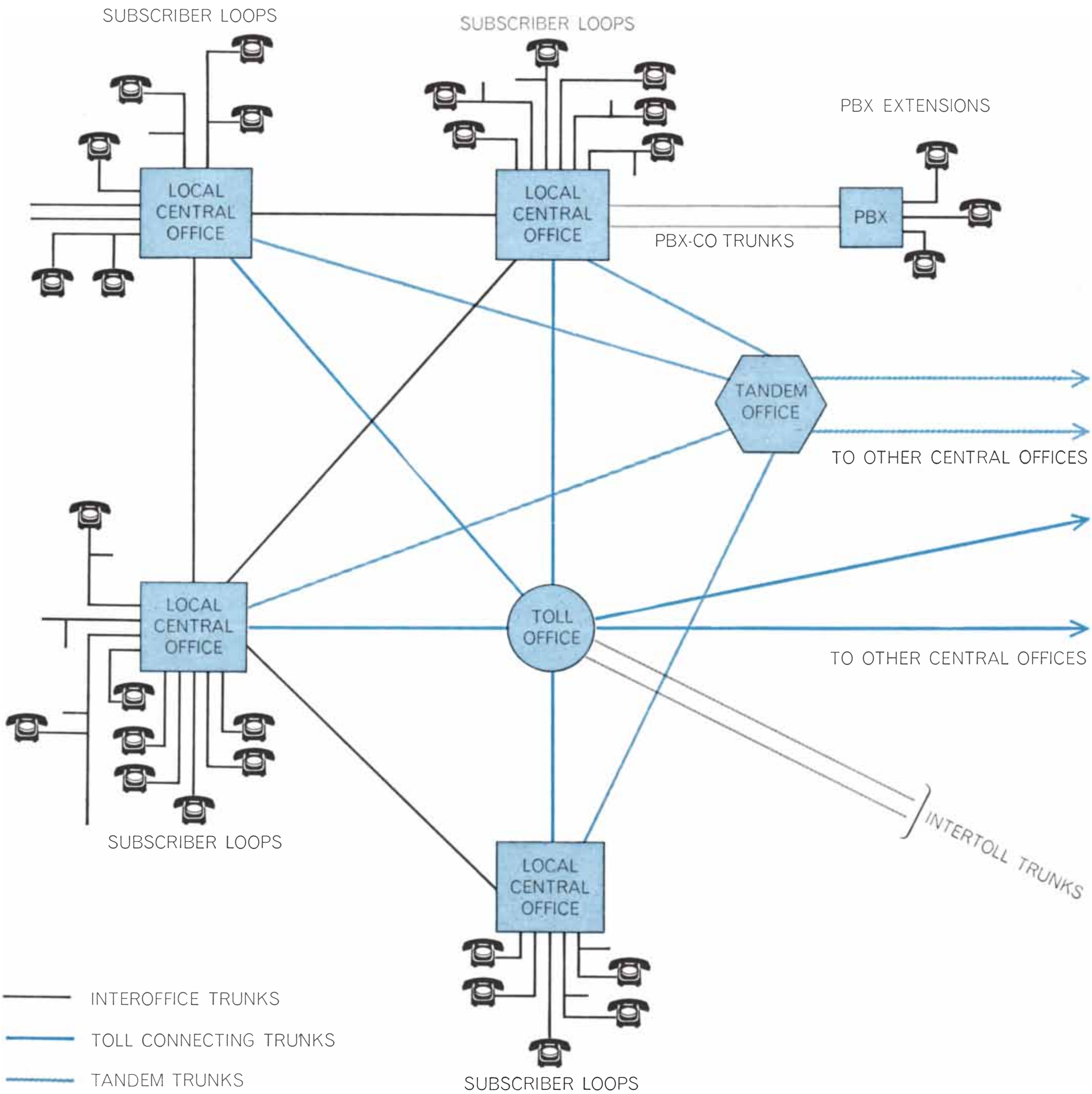
Transmit six billion bits per second each way through a two-inch wave guide by means of radio waves whose wavelength is measured in millimeters.

Transmit a total of six billion bits per second between various pairs of telephone offices by means of a single hovering artificial satellite.

For better or worse, it would be idle to assume that there will be all-digital transmission in any near future. For an all-digital system to be useful it would have to extend to anyone who wanted communication service. For the cost of such a system to be bearable the traffic would have to be great. One cannot start entirely afresh and build a universal digital-transmission system, first because the undertaking would be impractically large and second because the initial traffic such a system would handle is already accommodated by existing facilities.

What, then, do we have, and where are we going? There are in the country a number of private transmission systems (predominantly microwave-radio systems) owned by large users. The bulk of traffic, however, goes over common-carrier telephone and telegraph company lines. Of the traffic borne by common carriers the bulk of the facilities are those of the telephone companies, both Bell System and independent. These facilities have a capital value of some $30 billion. They consist of a great many kinds of equipment, old and new, which through a process of orderly development and evolutionary accommodation can work together in handling a variety of traffic.

A small part of the Bell System transmission equipment is already digital. The "T1" transmission system sends 1.5 million binary pulses per second for distances between five and 50 miles. A twisted pair of wires in a cable is used for each direction, and regenerative repeaters every mile amplify and reshape the train of pulses. The T1 system is widely installed. In Massachusetts, for



TELEPHONE NETWORK is designed in hierarchical fashion. When a call is placed to someone in the immediate neighborhood, the connection is usually made in the local central office. Calls to more distant points may involve "toll offices" or "tandem offices."

example, a network of T1 systems will soon cover the entire state. The system is used predominantly for telephony, but it is also used for data transmission, including facsimile. It is well suited to the visual telephone ("Picturephone"). Other digital-transmission systems are under development, including a T2 system with four times the bit capacity of the T1 and a T4 coaxial-cable system with nearly 200 times the capacity of the T1.

The rest of the common-carrier plant—transmission and switching—was designed primarily for sending analogue signals such as voice. The amplitude of an analogue signal varies over a period of time in a smooth way, and in certain respects this variation must be reproduced with high precision.

To achieve the universality necessary for effective communication, common-carrier facilities are interconnected in a hierarchical manner. Let me illustrate by describing the switched-message telephone plant.

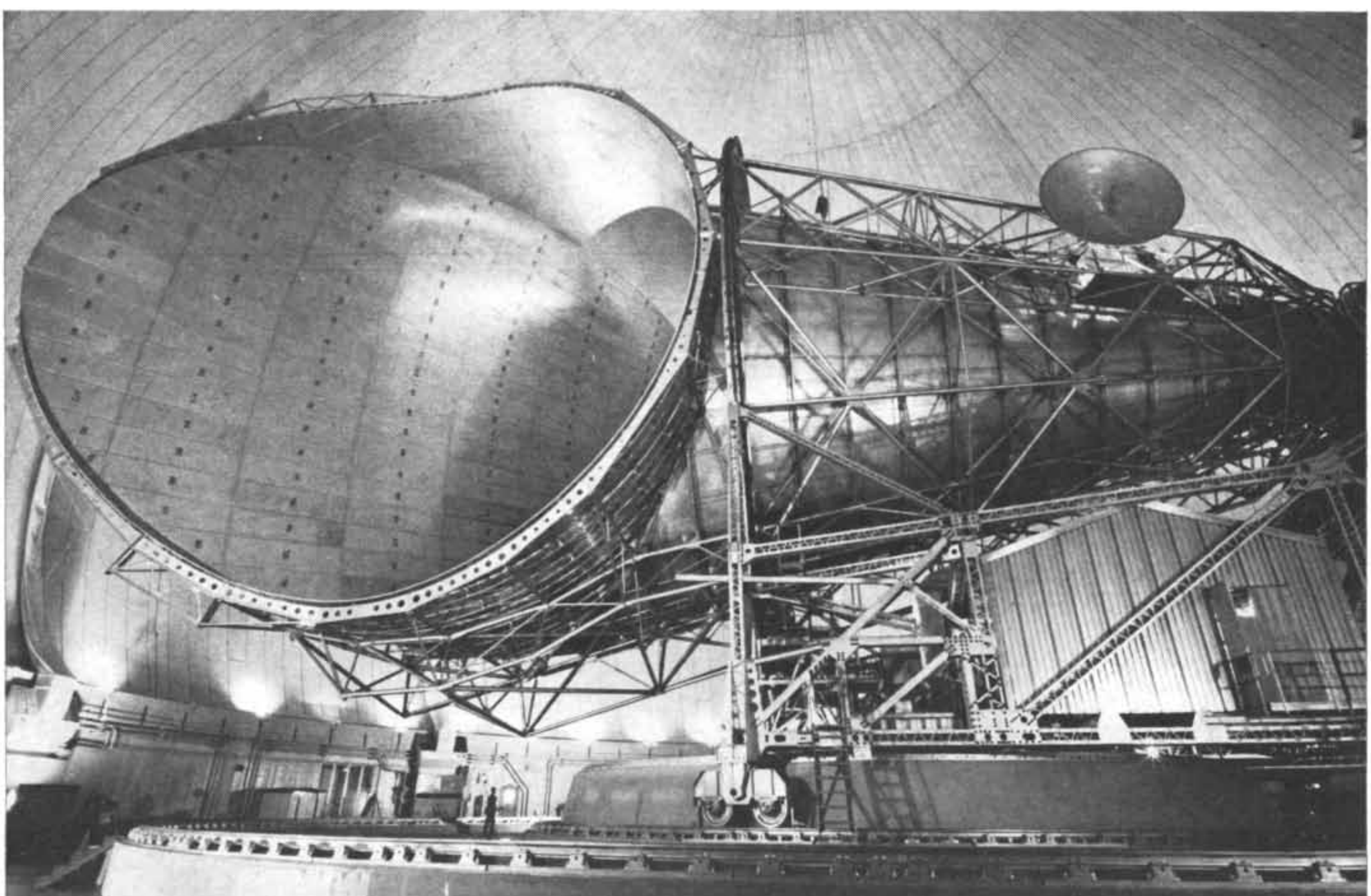
Although most of the world's 182 million telephones are interconnected, we shall consider only the 95 million telephones in North America. Among the 95 million telephones there are more than 4×10^{15} possible interconnections. It is ridiculous to imagine this number of individual circuits interconnecting the telephones of the country. Clearly some more sensible means of interconnection must be employed. The illustration on the preceding page gives a clue to what it is.

The "subscriber's loop" from your house goes to a local central office, along with between a few hundred and as many as 50,000 other subscriber's loops. When you talk with another subscriber who is connected to the same central offices in one area, it is uneco-his right at that office. In a large metropolitan area there will be many central offices. When there is heavy traffic between nearby offices, those offices will be connected by interoffice trunks.

When there are a large number of central offices in one area, it is uneconomical to provide an adequate number of trunks between all central offices, just as it is uneconomical to interconnect all telephones pair by pair. Instead a tandem office is set up, connected to each of the local central offices it serves by tandem trunks. Finally, one may wish to talk with someone else in a distant city. In that case the call will go from the local central office to a toll office and thence over an intertoll trunk to some other toll office.

There is also a hierarchical organization of the facilities used to transmit signals between various parts of the system. The subscriber's loop is a twisted pair of copper wires in a cable, without means of amplification. Amplifiers are sometimes needed for a long loop.) The subscriber's loop is a two-wire circuit, that is, voice signals are transmitted simultaneously in both directions over the same pair of wires. Because the means of suppressing interference between the signals going in opposite directions is not quite perfect, some of the signal going toward a subscriber is reflected back toward the sender. Although this defect is unobjectionable in voice communication, it makes it impractical to use simple two-wire circuits for the simultaneous two-way transmission of data.

The next level in the hierarchy employs four-wire systems, which provide independent circuits for the two direc-



SENSITIVE MICROWAVE ANTENNA at Andover, Me., is operated for the Communication Satellite Corporation by the Bell System. Originally designed to track Bell's Telstar, the antenna is now kept fixed on Early Bird, the synchronous satellite built for Comsat by the Hughes Aircraft Company. The author was among the first to urge the development of communication satellites.

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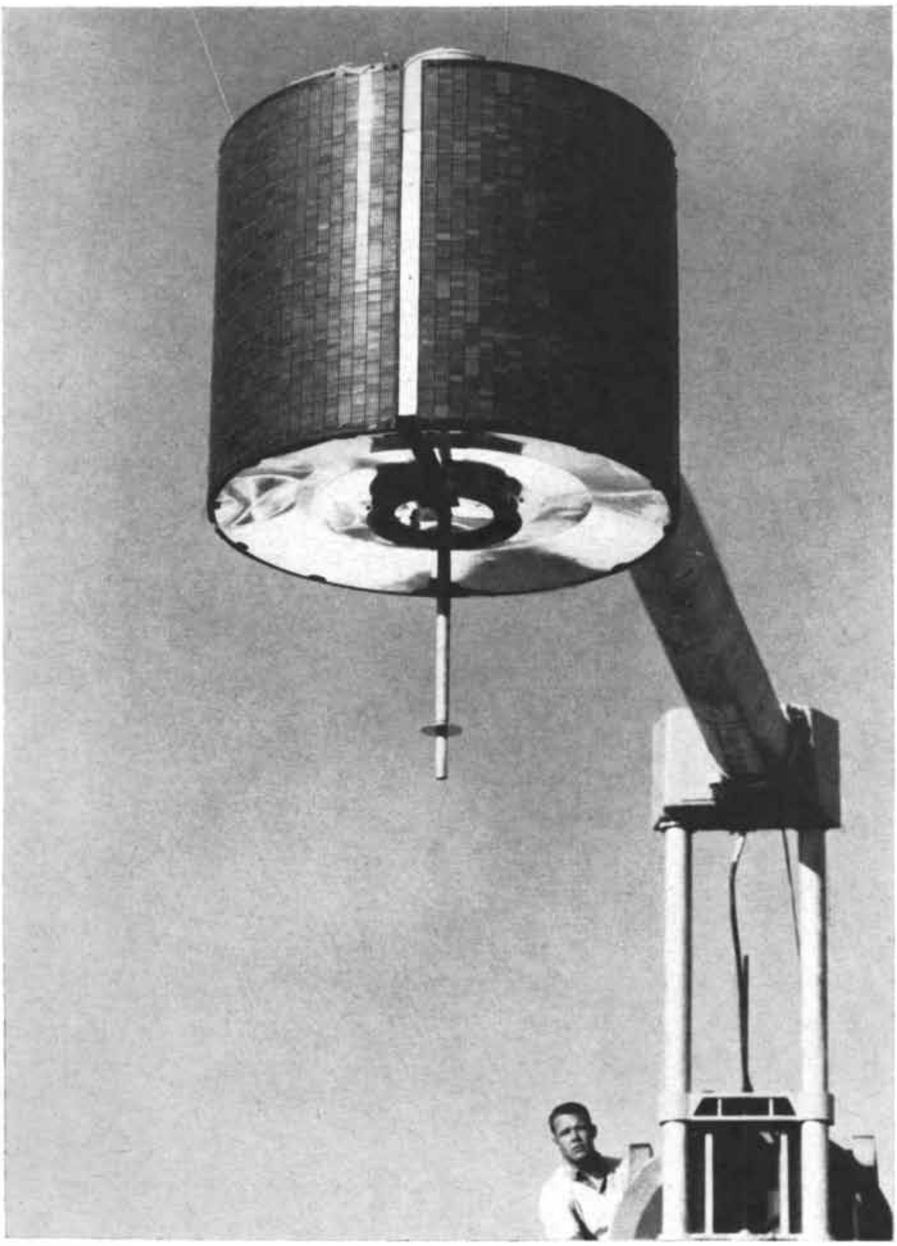
COMPUTER DIVISION EMR

tions of transmission. In these systems, which interconnect toll offices, the band of frequencies constituting a telephone channel is shifted up in frequency so that many channels can be "stacked" one above another in frequency and transmitted through amplifiers and over cables without interference. This technique is known as frequency-division multiplex.

For long-haul transmission hundreds of channels are transmitted over one coaxial cable, or one microwave link, or one submarine cable, or one communication satellite. At present all long-haul systems use frequency-division multiplex. They all employ a standard pattern in shifting the frequencies of voice channels and combining them. A "channel bank" is used to combine 12 voice channels into a group by shifting their frequencies. A "group bank" is used to combine five groups into a supergroup (60 channels) by another frequency shift. A "supergroup bank" is used to combine 10 supergroups into a master group (600 channels) by means of still another frequency shift. By a further frequency shift several master groups can be sent over one long-haul system.

Because of this hierarchical procedure various channels with a bandwidth broader than a telephone channel are readily available in the telephone network. These are the group, with a bandwidth of about 48,000 cycles; the supergroup, with a bandwidth of about 240,000 cycles, and the master group, with a bandwidth of about 2.4 million cycles. Such broad-band channels are commonly employed in data transmission and facsimile transmission. If the demand arises, data can be sent over the channels of still wider bandwidth (about 4.1 million cycles) developed to carry television signals.



EARLY BIRD, built by Hughes Aircraft, was placed in a synchronous orbit some 22,300 miles above the equator in April, 1965. At that altitude its period of rotation is exactly 24 hours, with the result that it appears to stay fixed above a point in the South Atlantic. From that position Early Bird can relay radio and television signals uninterruptedly between the U.S. and Europe. It seems likely that far more capacious synchronous satellites will eventually be needed to supply communication channels between cities within the U.S.

For some years in the future common-carrier circuits that were designed primarily for voice signals will be used to transmit a wide variety of new kinds of signal, including digital, facsimile and Picturephone signals. Special end links, such as those provided by the T1 digital system, will come into play, and long-haul digital transmission will be introduced gradually in such a way that it can operate interchangeably with present facilities. Nonetheless, new kinds of communication cannot wait for the construction of an entirely new common-carrier plant.

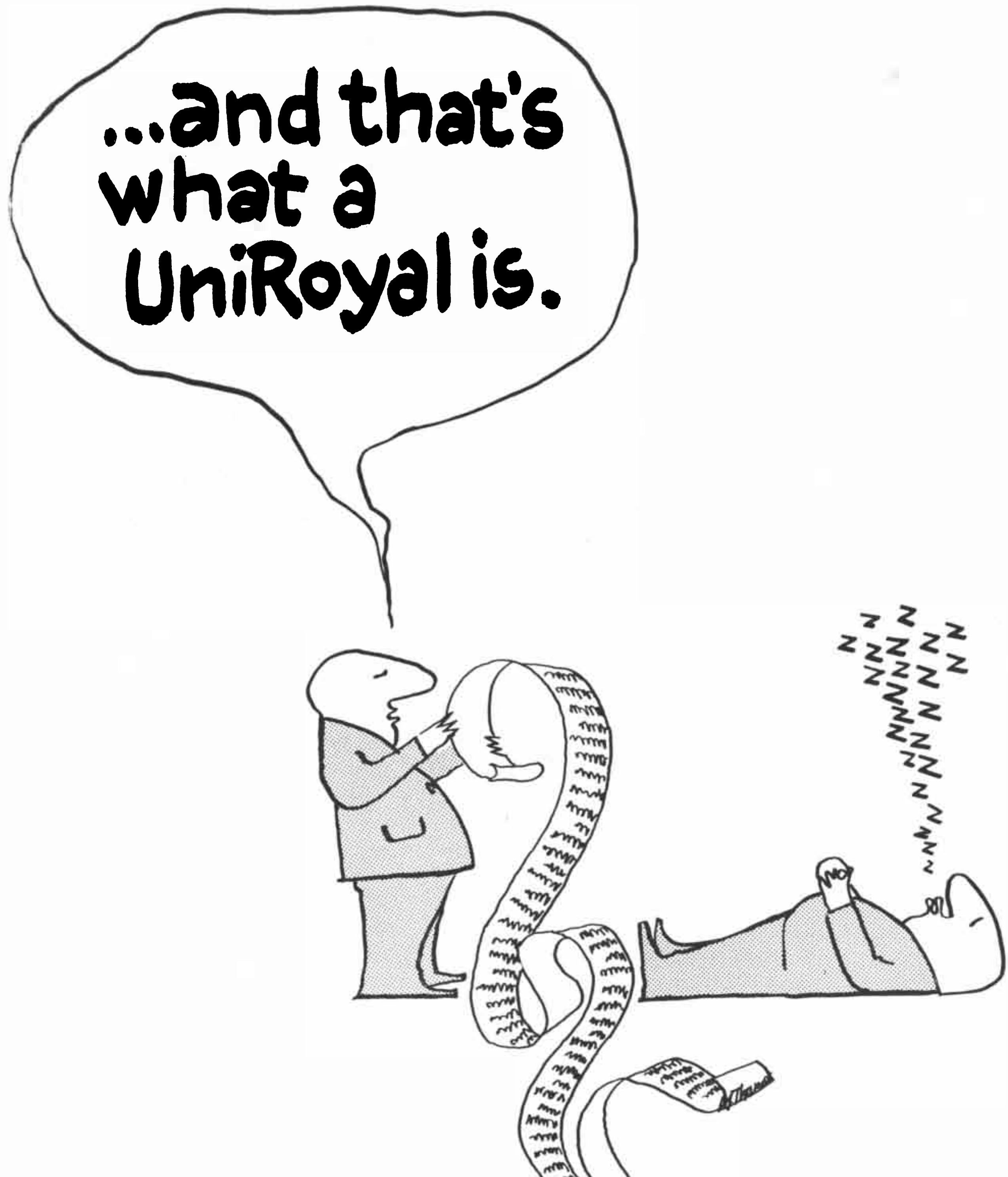
Present circuits derived from frequency-division multiplex systems are rather sophisticated from the point of view of information theory. They are tailored to the statistical analysis of voice signals and conversations. If they are required to carry a large number of data signals that "talk" all the time with the same "loudness," they can be overloaded.

Furthermore, the ear does not mind if some frequency components of a signal arrive a little earlier or a little later than others, but this is intolerable in the transmission of pulses. To transmit pulses efficiently over a circuit designed for voice a device called an equalizer must be used, and this device must be tailored to the particular circuit.

Finally, our sense of hearing is insensitive to moderate, gradual changes in level. In transmitting digital signals efficiently over a circuit, however, it may be necessary to distinguish among 16 or more precise amplitudes. The control of level is therefore another problem.

In the economics of data transmission the cost of the "data set," which adapts a circuit for data transmission, may be paramount. On the other hand, a high rate of transmission in bits per second may be the most important factor. Therefore cheap data terminals that will squeeze more bits per second through a circuit are also needed.

Let us consider sending data over a



...and that's what a UniRoyal is.

telephone circuit. A simple data set will transmit up to 300 bits per second over any circuit. A slightly better set will transmit up to 600 bits per second. A set that does not use a binary signal but transmits four different kinds (frequencies) of signals will transmit up to 2,400 bits per second. All these data sets are available commercially [*see illustration on page 147*].

Beyond this level of performance experiments have been done showing that it is possible to transmit over a telephone channel up to 5,400 bits per second, and perhaps more than 9,000 bits per second. Such transmission calls for error-correcting codes and automatic equalizers, which adjust themselves to the characteristics of the particular circuit.

These rates are not high enough for many applications. Accordingly data sets are available that will transmit up to 19,200 bits per second over six voice channels, up to 50,000 bits per second over 12 voice channels (a group) and up to 230,400 bits per second over 60 voice channels (a supergroup). Finally, it is possible to use a standard television channel for transmission at rates up to several million bits per second. In addition to development work on a long-haul coaxial-cable system for more economical data transmission over long distances, experimental work is under way on the transmission of more bits per second over existing long-haul coaxial and microwave systems.

Providing broad-band transmission of various kinds is complicated by the fact that long-haul transmission systems in general link only toll offices. Therefore, although it is easy to extend voice circuits from any central office to a subscriber over existing wires, special arrangements must be made in order to supply broad-band data or other services to a subscriber. Fortunately the T1 digital-transmission system, which works over a pair of wires in a cable, provides an economical means for doing so. An alternative is simple short-haul microwave systems.

Transmission is, of course, only part of the problem. Various services are now available that supply circuits for a user's exclusive use. Telephone message service provides connections of any duration for the transmission of voice, data or other kinds of information. Some users, however, want channels of greater bandwidth than voice channels on a switched, or nonprivate, basis.

At present Western Union's Telex

RECENT
findings

RESEARCH LABORATORIES

Ford

NUCLEAR MAGNETIC RESONANCE INVESTIGATIONS OF METALS UNDER HIGH HYDROSTATIC PRESSURE

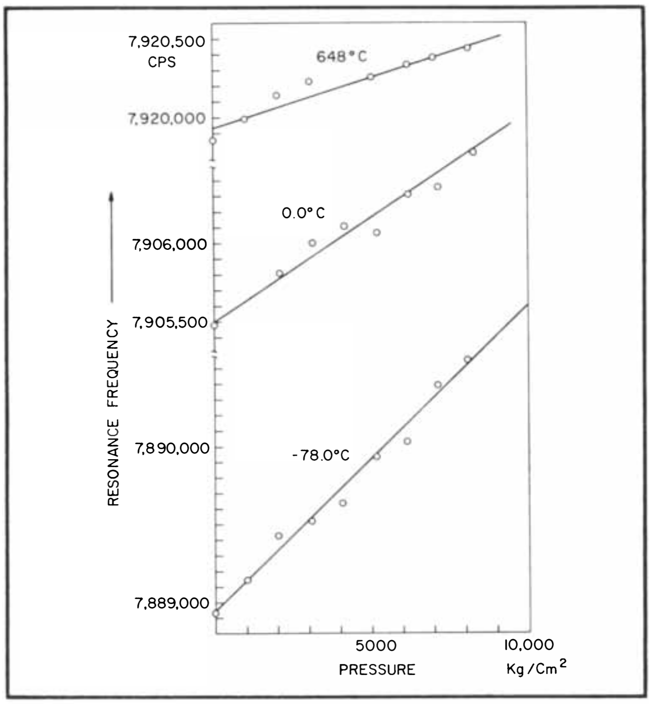
Ford Motor Company scientists measure interatomic distances in investigations of interaction between atoms in solid states.

The properties of a particular solid are, at least in principle, determined by particular properties of constituent atoms of the solid and interactions among these atoms. Since these interactions are dependent on interatomic distances, Ford scientists have developed techniques employing nuclear magnetic resonance (NMR) and the application of high hydrostatic pressure to study the properties of solids as a function of these interatomic distances.

The solid studied in the instance covered here was platinum metal. A nuclear magnetic resonance apparatus was used to measure the local magnetic field inside the solid. Hydrostatic pressure was generated by a modified Bridgman type generator. Radio wave energy, applied to the sample under study, is absorbed by the nuclei. The resonance frequency tells exactly the magnitude of the magnetic field at the position of the nucleus. Therefore, the nuclei, situated at the center of the atoms in the solid, can be used as built-in microscopic magnetic field probes.

An example of the measurements is shown in the figure at right. The NMR frequency of Pt^{195} nuclei in platinum is plotted as a function of the applied pressure up to 8,000 atmospheres (120,000 pounds per square inch) at three temperatures, while the externally applied magnetic field is kept constant. The resonance frequency increased with increasing pressure, implying that the local magnetic field seen at the Pt^{195} nucleus increases with pressure, in a temperature dependent manner.

By analyzing these curves it is possible to deduce how the state of the itinerate s and the localized d electrons in this metal changes as a function of interatomic distance. It is possible to estimate how many localized electrons are liberated into the itinerate states and how the energy of these s and d electrons changes when the solid is compressed. Similar experiments are now being conducted with other metals such as cadmium and niobium.



These studies are designed to give Ford scientists a more complete basic understanding of the microscopic properties of the metallic state and are typical of work in progress in our laboratories. Ford scientists cover many fields in the conviction that greater knowledge leads inevitably to improved technology and better products.

PROBING DEEPER TO SERVE BETTER

Ford

The American Road, Dearborn, Michigan

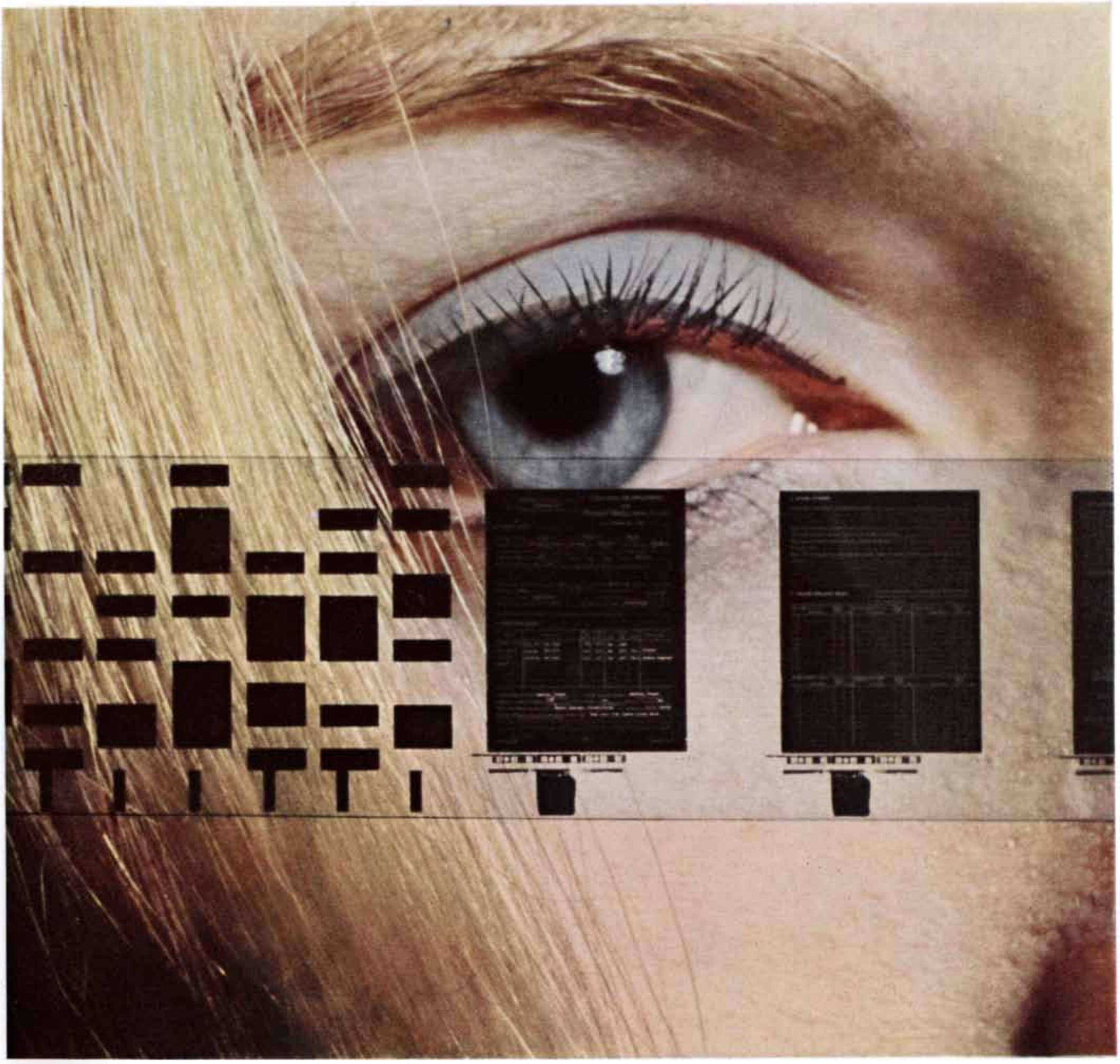
system provides medium-band switched service, but only between locations near certain key cities. Telephone companies have provided switched data service for group bandwidths on a "private line," or "private network," basis and plan to introduce a general wide-band switched data network.

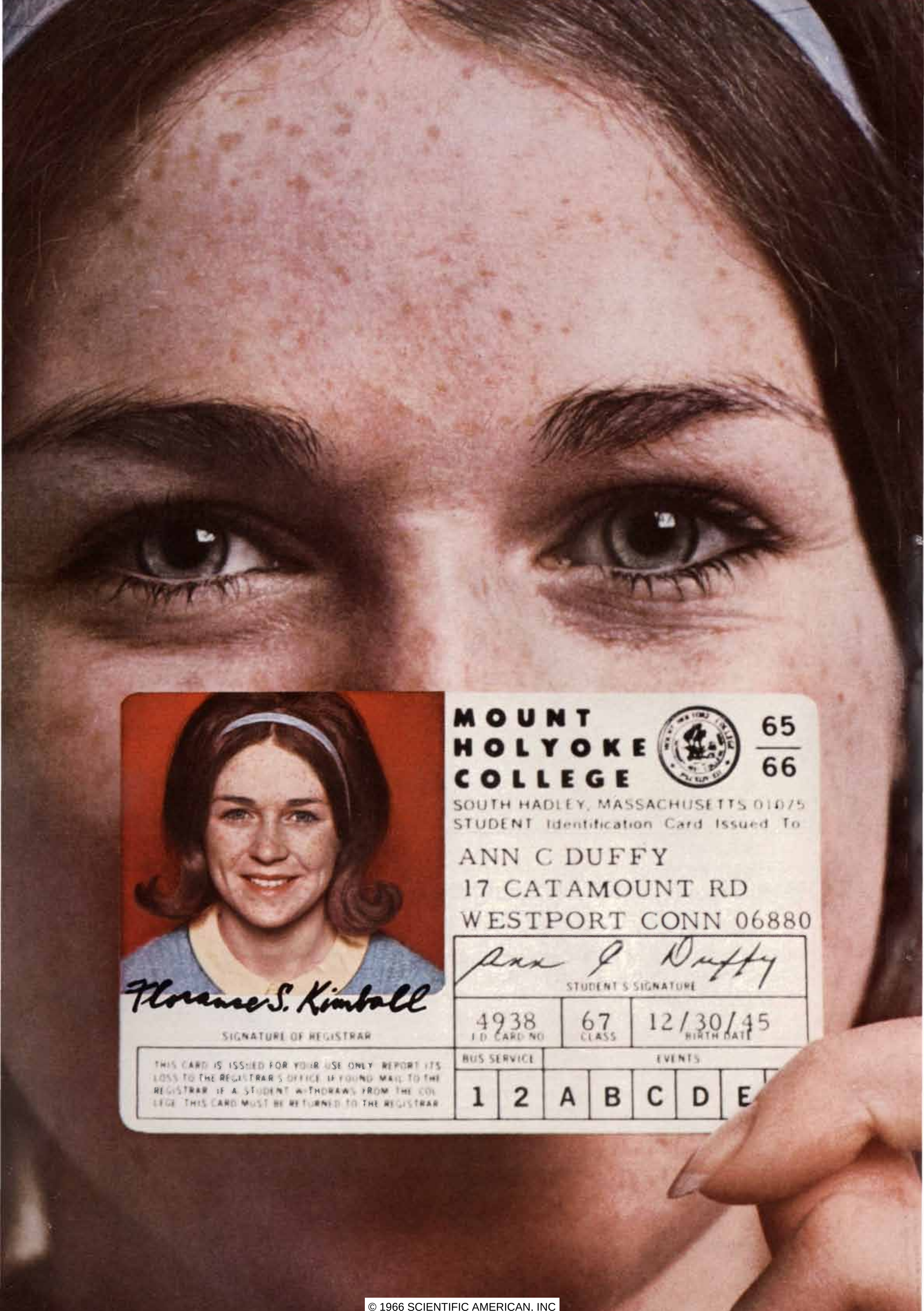
New uses of communication provide new operational problems. Switched data circuits may be in operation for hours at a time; this is much longer than a telephone call. Some users would occasionally like to have a narrow-band or a broad-band circuit for a minute or less at a time. This means that the switching time required for setting up the connection might be comparable to the time the connection was in use. No doubt electronic switching, employing transistors, will ultimately lead to much shorter switching times than is now possible with electromechanical switching systems employing relays, but the electronic switching capacity now installed is small, and electromechanical switching will predominate for many years.

One obstacle to rapid progress in new uses of communication is the weight of tradition. New uses, even of existing equipment, call for new "packaging." The user wants to buy a service he needs right now, not a service someone else needed years ago. It is not easy to devise standard packages that are acceptable and economical. Moreover, no new service can be offered without the consent of regulatory bodies, and without their first assuring themselves that the new service is "compensatory" according to traditional standards.

The evolution of electronic computers, together with many other advances, is extending communication and the need for communication facilities of a great variety. Even in communication with computers, however, one cannot be sure how much of the communication will be data, how much voice and how much graphical material. The immediate problem is to send all kinds of signals, including data signals, over existing circuits. Only in that way can we have from the start the universality of communication to which telephony has accustomed us.

The fact remains that digital transmission is increasingly attractive for sending all kinds of signals. Indeed, we are probably in a period of evolution that will lead us more and more toward completely digitalized communication service—from the subscriber, through the switching operations and to the farthest reaches of the earth.





MOUNT HOLYOKE COLLEGE
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SOUTH HADLEY, MASSACHUSETTS 01075
STUDENT Identification Card Issued To
ANN C DUFFY
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WESTPORT CONN 06880
Ann C Duffy
STUDENT'S SIGNATURE
Florence S. Kimball
SIGNATURE OF REGISTRAR
4938
I.D. CARD NO
67
CLASS
12/30/45
BIRTH DATE
THIS CARD IS ISSUED FOR YOUR USE ONLY. REPORT ITS LOSS TO THE REGISTRAR'S OFFICE. IF FOUND MAIL TO THE REGISTRAR. IF A STUDENT WITHDRAWS FROM THE COLLEGE THIS CARD MUST BE RETURNED TO THE REGISTRAR
BUS SERVICE
EVENTS
1 2 A B C D E

In two minutes, a laminated ID card that identifies Ann Duffy right down to her freckles.

Two minutes after somebody comes face to face with the Polaroid ID-2 Land Identification System, he is presented with a ready-to-carry ID card.

This ID will include the surest means of identification—a full-color photo showing exact shade of eyes, skin, and hair. As well as whatever printed data are needed.

There's no waiting for photographic processing. No waiting for the card to come through the mail. No need to schedule reshooting if the picture doesn't come out right—that can be done immediately.

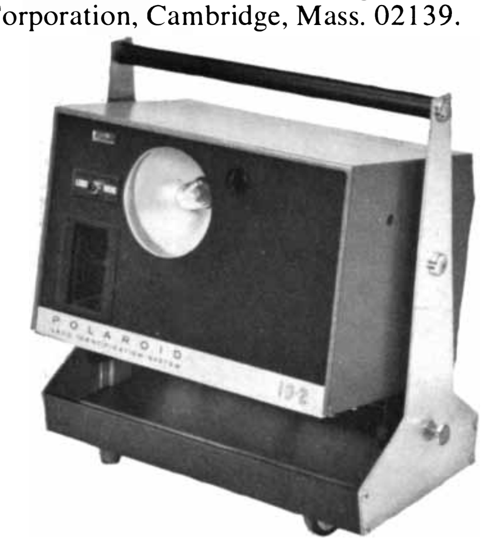
This system enabled Mount Holyoke College to issue cards with color-keyed backgrounds to the entire faculty, staff, and student body in a couple of days during registration. They got cards like the freckled Miss Duffy's.

There are five parts to the system: the camera (that's it at bottom), a timer, a laminator, a die cutter, and a sealer. And operation is so simple that the people who work it can be recruited from the typing pool or student body (as they were at Mount Holyoke). Here's how it works:

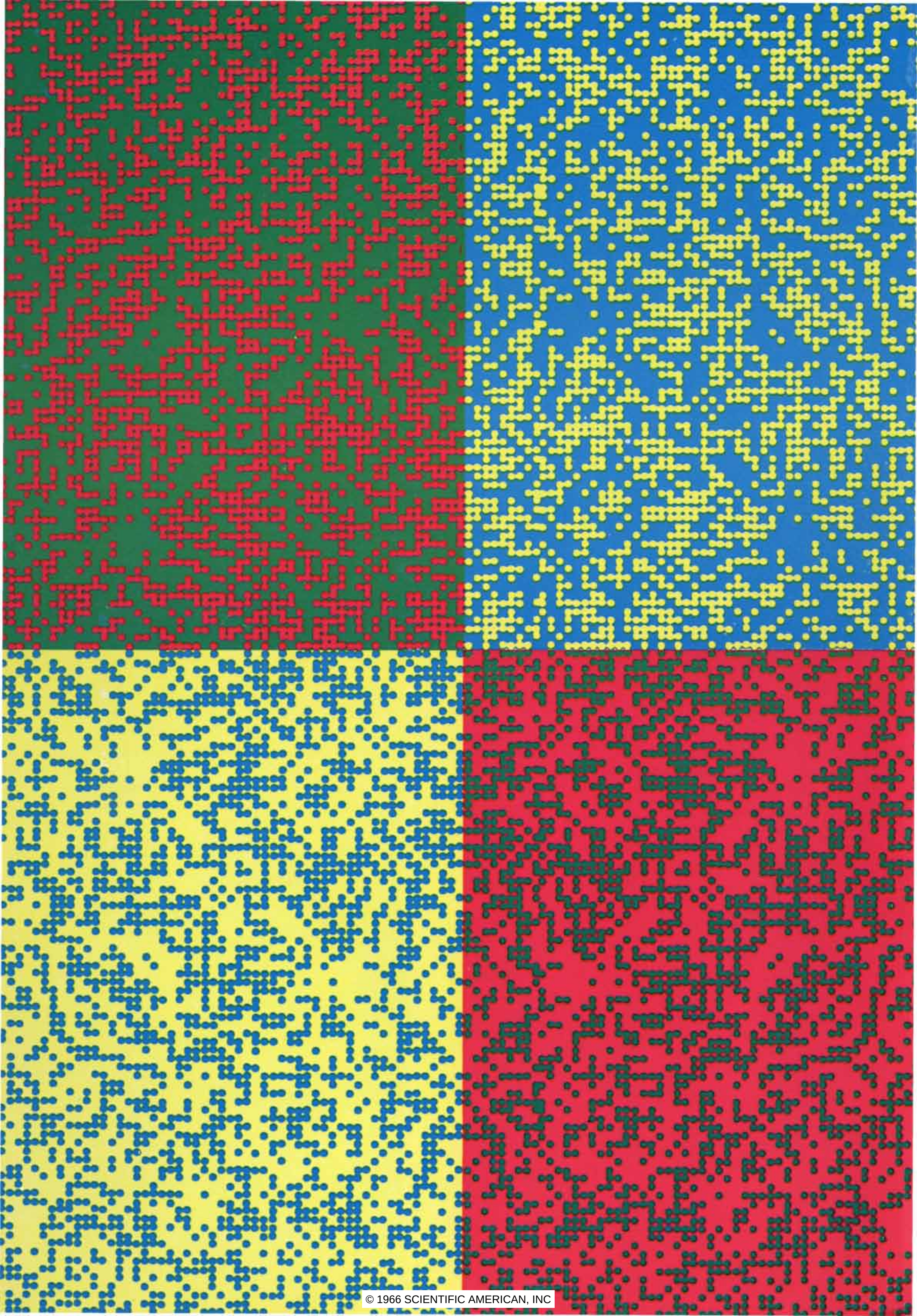
An individual's vital statistics are typed on a data processing card. The card goes into the camera and the subject steps in front. Then, in a single exposure, the camera records both the subject's face and the data card (the card can then go into a central processing system). Incidentally, this makes on-the-spot identifications as tamperproof as any yet devised. Because picture and data are incorporated in a single photograph (which is then laminated in plastic) they can't be separated without detection.

After making the exposure, you pull out the film packet, wait 60 seconds, peel it apart and insert it into the laminator. In a simple, three-step process the card is laminated, trimmed and sealed in a plastic pouch. The individual pockets his card and he's through.

And it all takes less time (about two minutes) than it would take you to write us for more information. Technical Sales, Dept. 22, Polaroid Corporation, Cambridge, Mass. 02139.



The Polaroid Identification System



The Uses of Computers in Science

The main impact of the computer on science promises to come not in its role as a powerful research instrument but rather as an active participant in the development of scientific theories

by Anthony G. Oettinger

In its scientific applications the computer has been cast in two quite distinct but complementary roles: as an instrument and as an actor. Part of the success of the computer in both roles can be ascribed to purely economic factors. By lowering the effective cost of calculating compared with experimenting the computer has induced a shift toward calculation in many fields where once only experimentation and comparatively direct measurement were practical.

The computer's role as an instrument is by far the more clear-cut and firmly established of the two. It is in its other role, however, as an active participant in the development of scientific theories, that the computer promises to have its most profound impact on science. A physical theory expressed in the language of mathematics often becomes dynamic when it is rewritten as a computer program; one can explore its inner structure, confront it with experimental data and interpret its implications much more easily than when it is in static form. In disciplines where mathematics is not the prevailing mode of expression the language of computer programs serves increasingly as the language of science. I shall return to the subject of the dynamic expression of theory after considering the more familiar role of the computer as an instrument in experimental investigations.

The advance of science has been marked by a progressive and rapidly accelerating separation of observable phenomena from both common sensory experience and theoretically supported intuition. Anyone can make at least a qualitative comparison of the forces required to break a matchstick and a steel bar. Comparing the force needed to ionize a hydrogen atom with the force that binds the hydrogen nucleus together is much more indirect, because the chain from phenomenon to observation to interpretation is much longer. It is by restoring the immediacy of sensory experience and by sharpening intuition that the computer is reshaping experimental analysis.

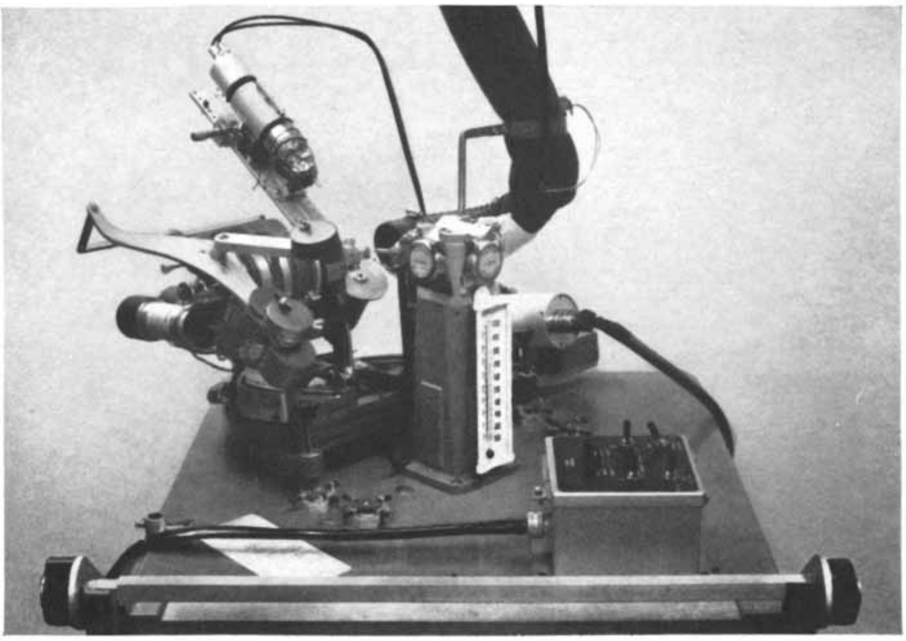
The role of the computer as a research instrument can be readily understood by considering the chain from raw observations to intuitively intelligible representations in the field of X-ray crystallography. The determination of the structure of the huge molecules of proteins is one of the most remarkable achievements of contemporary science. The highlights of this work have been reported in a number of articles in *Scientific American,* notably "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew [December, 1961], and "The Hemoglobin Molecule," by M. F. Perutz [November, 1964]. The labor, care and expense lavished on the preparation of visual models of protein molecules testify to a strong need for intuitive aids in this field. The computational power required to analyze crystallographic data is so immense that the need for high-speed computers is beyond doubt.

The scope and boldness of recent experiments in X-ray crystallography have increased in direct proportion to increases in computer power. Although computers seem to be necessary for progress in this area, however, they are by no means sufficient. The success stories in the determination of protein structures have involved an interplay of theoretical insight, experimental technique and computational power.

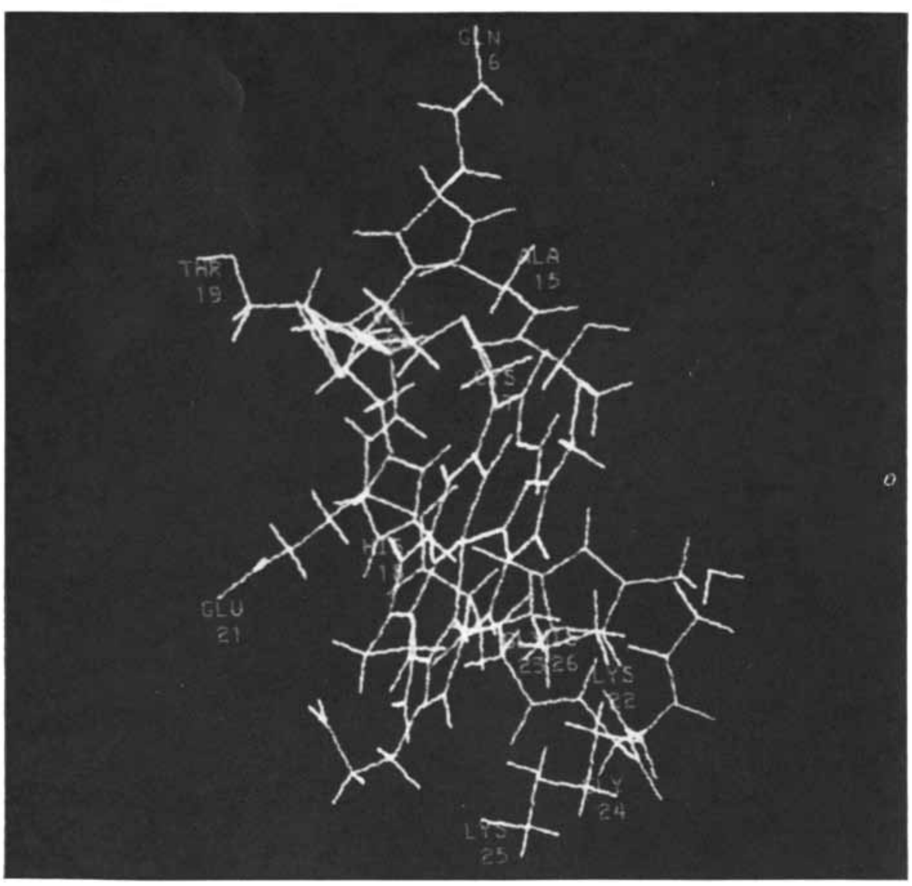
In work of this kind a rotating protein crystal is bombarded by a beam of X rays; the rays diffracted by the crystal are recorded on a photographic plate, where they produce characteristic patterns of bright spots on the dark background. Measurements of the relative positions and intensities of the spots in the diffraction pattern are the raw material for calculations that have as their result a table of coordinates of the three-dimensional distribution of electrons in the molecule. The electron-density data are then used to draw density-contour maps, which are interpreted as a three-dimensional model of the particular protein molecule under study.

Many of the links in this chain are now automated. The laborious manual measurement of photographs, for example, is no longer necessary. In the laboratory of William N. Lipscomb, Jr., at Harvard University a mounted crystal is rotated automatically through the required sequence of orientations while a photomultiplier tube measures the intensity of the diffracted X rays [*see top illustration on next page*]. Machines convert information about position and intensity into digital form and record it on punched cards for input to a computer.

SYMMETRICAL PATTERN of colored dots on the opposite page was produced by a computer for use in an experiment on visual perception. The pattern has fourfold symmetry around the central point, similar to the pattern produced in a kaleidoscope. In the actual experiment transparent slides containing the pattern are projected in various colors to see how well the perception of symmetry survives the different combinations. In such experiments the colors are adjusted to have equal subjective brightness; this is difficult to do with inks and was not attempted in this reproduction. The experiment is part of a study of texture and visual perception being conducted by Bela Julesz of the Bell Telephone Laboratories.



X-RAY DIFFRACTION APPARATUS in the laboratory of William N. Lipscomb, Jr., at Harvard University makes unnecessary the laborious manual measurement of X-ray diffraction photographs of crystal structures. A beam of X rays (*from housing at center*) is directed at a mounted crystal (for example a protein), which is rotated automatically through a series of orientations while a photomultiplier tube (*top left*) measures the intensity of the diffracted rays. Information about the position and intensity of the diffracted rays is then converted from analogue to digital form and recorded on punched cards for input to a computer.



MODEL OF PROTEIN MOLECULE is displayed on an oscilloscope screen in the laboratory of Cyrus Levinthal at the Massachusetts Institute of Technology. The electron density of the molecule was determined by an analysis of X-ray diffraction photographs. A computer program converted the electron-density measurements into an image of a fragment of the molecular structure on the oscilloscope. Once the picture of the molecule has been calculated for a standard orientation the orientation can be changed at will by simple controls.

At the other end of the chain Cyrus Levinthal of the Massachusetts Institute of Technology and Robert Langridge of Harvard have used the time-shared computer and display facilities of M.I.T.'s Project MAC to develop a remarkable set of programs that accept electron densities calculated for a three-dimensional region and turn these into an image of molecular structure on an oscilloscope [*see bottom illustration at left*]. Gone is the time-consuming task of drawing and building the electron-density map. Once the picture of a molecule has been calculated for a standard orientation the orientation can be changed at will by simple controls that actuate special circuits for transforming the coordinates of the picture before displaying it. Slight motions provide excellent depth perception without the expense of stereoscopic image pairs. The molecule can be turned in order to view it from any angle, or it can be sliced by a plane in order to see it in cross section [see "Molecular Model-building by Computer," by Cyrus Levinthal; SCIENTIFIC AMERICAN, June].

Joining these two links is the next step. A new coaxial-cable network will soon carry Lipscomb's raw data directly to a computer at the Harvard Computing Center. No technical obstacle bars the further transmission of calculated electron densities to the system at M.I.T., where the molecular display could be prepared and then sent back for direct viewing on a screen at the experimental site. Once the time-shared computer utility emerges from its present experimental stage to spread throughout institutions and regions, such doings will very likely be commonplace [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128]. It is only tame speculation to visualize a graduate student "looking through" a computer at a protein molecule as directly as he now looks at a cell through a microscope.

The metaphor of the transparent computer describes one of the principal aims of contemporary "software" engineering, the branch of information engineering concerned with developing the complex programs (software) required to turn an inert mound of apparatus (hardware) into a powerful instrument as easy to use as pen and paper. As anyone can testify who has waited a day or more for a conventional computing service to return his work only to find that a misplaced comma had kept the work from being done at all, instant transparency for all is not yet here. Nevertheless, the advances described in the accompanying articles toward making computer languages congenial and expressive, toward making it easy to communicate with the machine and toward putting the machine at one's fingertips attest to the vigor of the pursuit of the transparent computer.

A few critics object to the principle of transparency because they fear that the primary consequence will be atrophy of the intellect. It is more likely that once interest in the *process* of determining molecular structure becomes subordinate to interest in the molecule itself, the instrument will simply be accepted and intellectual challenge sought elsewhere. It is no more debasing, unromantic or unscientific in the 1960's to view a protein crystal through the display screen of a computer than it is to watch a paramecium through the eyepiece of a microscope. Few would wish to repeat the work of Christian Huygens each time they need to look at a microscope slide. In any case, computers are basically so flexible that nothing but opaque design or poor engineering can prevent one from breaking into the chain at any point, whenever one thinks human intuition and judgment should guide brute calculation.

It is essential, of course, for anyone to understand his instrument well enough to use it properly, but the computer is just like other commonplace instruments in this regard. Like any good tool, it should be used with respect. Applying "data reduction" techniques to voluminous data collected without adequate experimental design is a folly of the master not to be blamed on the servant. Computer folk have an acronym for it: GIGO, for "garbage in, garbage out."

X-ray crystallography is the most advanced of many instances in which similar instrumentation is being developed. Four experimental stations at the Cambridge Electron Accelerator, operated jointly by Harvard and M.I.T., are currently being connected to a time-shared computer at the Harvard Computing Center to provide a first link. A small computer at each experimental station converts instrument readings from analogue to digital form, arranges them in a suitable format and transmits them to the remote computer. There most data are stored for later detailed calculation; a few are examined to instruct each of the small local machines to display information telling the experimenter whether or not his experiment is going well. Heretofore delays in conventional batch-processing procedures occasionally led to scrapping a long experiment that became worthless because poor adjustments could not be detected until all calculations were completed and returned.

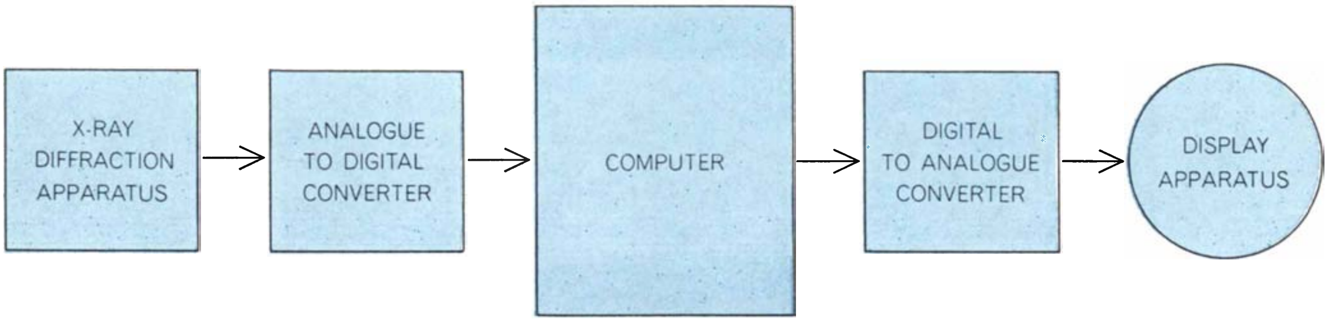
This type of experiment is described as an "open loop" experiment, since the computer does not directly affect the setting of experimental controls. Closed-loop systems, where the experiment is directly controlled by computer, are currently being developed. Their prototypes can be seen in industrial control systems, where more routine, better-understood devices, ranging from elevators to oil refineries, are controlled automatically.

The problem of "reading" particle-track photographs efficiently has been a persistent concern of high-energy physicists. Here the raw data are not nearly as neat as they are in X-ray diffraction patterns, nor can photography as readily be bypassed. Automating the process of following tracks in bubble-chamber photographs to detect significant events presents very difficult and as yet unsolved problems of pattern recognition, but computers are now used at least to reduce some of the tedium of scanning the photographs [*see illustration on next page*]. Similar forms of man-machine interaction occur also in the study of brain tumors by radioactive-isotope techniques. Where the problem of pattern recognition is simpler, as it is in certain types of chromosome analysis, there is already a greater degree of automation [see "Chromosome Analysis by Computer," by Robert S. Ledley and Frank H. Ruddle; SCIENTIFIC AMERICAN, April].

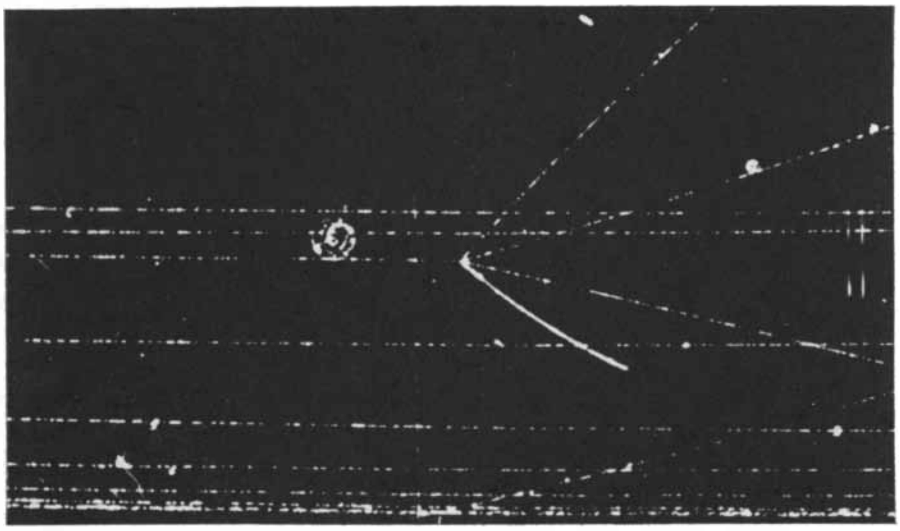
Let us now turn from the computer as instrument to the computer as actor, and to the subject of dynamic expression of theory. To understand clearly words such as "model," "simulation" and others that recur in this context, a digression is essential to distinguish the functional from the structural aspects of a model or a theory.

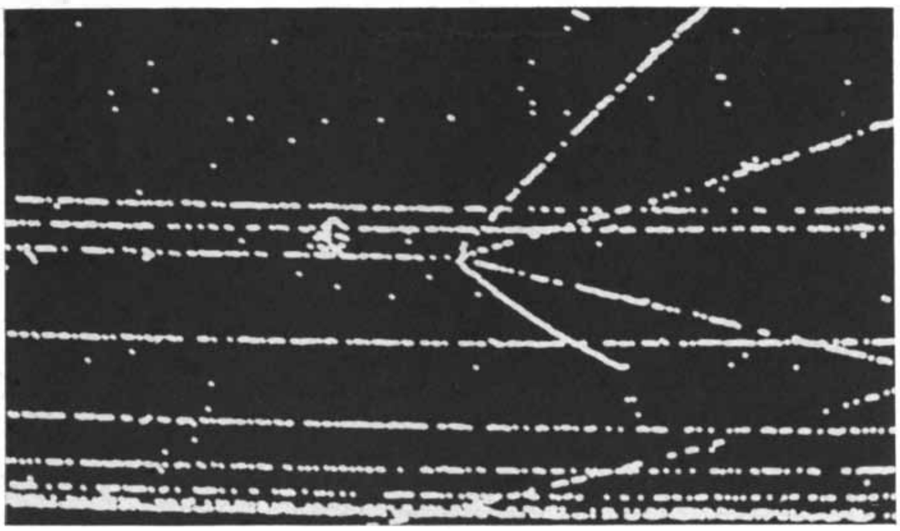
A robot is a functional model of man. It walks, it talks, but no one should be fooled into thinking that it is a man or that it explains man merely because it acts like him. The statements that "the brain is like a computer" or that "a network of nerve cells is like a network of computer gates, each either on or off," crudely express once popular structural theories, obviously at different levels. Both are now discredited, the first because no one has found structures in the brain that look anything like parts of any man-made computer or even function like them, the second because nerve-cell networks were found to be a good deal more complicated than computer networks.

A functional model is like the electrical engineer's proverbial "black box," where something goes in and something comes out, and what is inside is unknown or relevant only to the extent of somehow relating outputs to inputs. A structural model emphasizes the contents of the box. A curve describing the



LINKUP of the two facilities represented on the opposite page is the next step toward the goal of a "transparent" computer in the field of X-ray crystallography. A new coaxial-cable network will soon carry Lipscomb's raw data directly to a computer at the Harvard Computing Center. No technical obstacle bars the further transmission of the calculated electron densities to the system at M.I.T., where the molecular display could be prepared and then sent back for direct viewing on a screen at the experimental site. It should then be possible to "look through" a computer at a protein molecule as directly as one now looks at a cell through a microscope.





BUBBLE-CHAMBER PHOTOGRAPH (*top*) of a typical particle interaction was made at the Lawrence Radiation Laboratory of the University of California. The negative of the photograph was scanned by a device called the "flying spot digitizer," and the digitized information was sent directly to a computer, which produced a copy of the original photograph (*bottom*). No operator is required in the scanning process. The machine is directed to the location of a significant event by instructions on magnetic tape. Other computer programs further analyze the data to provide a description of the interaction recorded in photograph.

current passing through a semiconductor diode as a function of the voltage applied across its terminals is a functional model of this device that is exceedingly useful to electronic-circuit designers. Most often such curves are obtained by fitting a smooth line to actual currents and voltages measured for a number of devices. A corresponding structural model would account for the characteristic shape of the curve in terms that describe the transport of charge-carriers through semiconductors, the geometry of the contacts and so forth. A good structural model typically has greater predictive power than a functional one. In this case it would predict changes in the voltage-current characteristic when the geometry of the interfaces or the impurities in the semiconductors are varied.

If the black box is opened, inspiration, luck and empirical verification can turn a functional model into a structural one. Physics abounds with instances of this feat. The atom of Lucretius or John Dalton was purely functional. Modern atomic theory is structural, and the atom with its components is observable. The phlogiston theory, although functional enough up to a point, evaporated through lack of correspondence between its components and reality. Although the description of the behavior of matter by thermodynamics is primarily functional and its description by statistical mechanics is primarily structural, the consistency of these two approaches reinforces both.

The modern computer is a very versatile and convenient black box, ready to act out an enormous variety of functional or structural roles. In the physical sciences, where the script usually has been written in mathematics beforehand, the computer merely brings to life, through its program, a role implied by the mathematics. Isaac Newton sketched the script for celestial mechanics in the compact shorthand of differential equations. Urbain Leverrier and John Couch Adams laboriously fleshed out their parts in the script with lengthy and detailed calculations based on a wealth of astronomical observations. Johann Galle and James Challis pointed their telescopes where the calculations said they should and the planet Neptune was discovered. In modern jargon, Leverrier and Adams each ran Neptune simulations based on Newton's model, and belief in the model was strengthened by comparing simulation output with experiment. Computers now routinely play satellite and orbit at Houston, Huntsville and Cape Kennedy. Nevertheless, there is little danger of confusing Leverrier, Adams or a computer with any celestial object or its orbit. As we shall see, such confusion is more common with linguistic and psychological models.

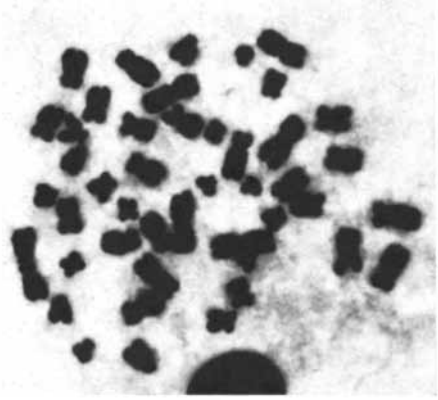
The determination of protein structures provides an excellent example of how computers act out the implications of a theory. Finding a possible structure for a protein molecule covers only part of the road toward understanding. For example, the question arises of why a protein molecule, which is basically just a string of amino acid units, should fold into the tangled three-dimensional pattern observed by Kendrew. The basic physical hypothesis invoked for explanation is that the molecular string will, like water running downhill, fold to reach a lowest energy level. To act out the implications of this hypothesis, given an initial spatial configuration of a protein chain, one might think of calculating the interactions of all pairs of active structures in the chain, minimizing the energy corresponding to these interactions over all possible configurations and then displaying the resultant molecular picture. Unfortunately this cannot be done so easily, since no simple formula describing such interactions is available and, with present techniques, none could be written down and manipulated with any reasonable amount of labor. Sampling more or less cleverly the energies of a finite but very large number of configurations is the only possibility. An unsupervised computer searching through a set of samples for a minimum would, more likely than not, soon find itself blocked at some local minimum—unable, like a man in a hollow at the top of a mountain, to see deeper valleys beyond the ridges that surround him.

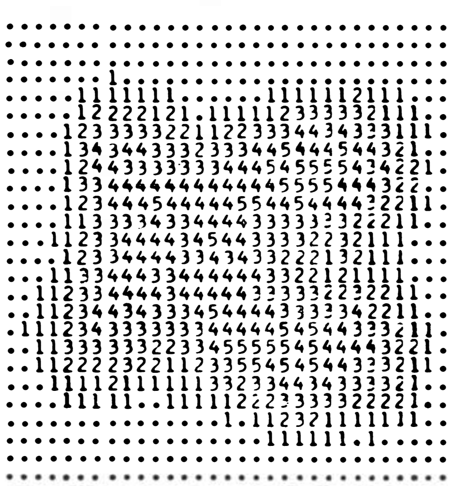
The close interaction of man and machine made possible by new "on line" time-sharing systems, graphical display techniques and more convenient programming languages enables Levinthal and his collaborators to use their intuition and theoretical insight to postulate promising trial configurations. It is then easy for the computer to complete the detail work of calculating energy levels for the trial configuration and seeking a minimum in its neighborhood. The human operator, from his intuitive vantage point, thus guides the machine over the hills and into the valley, each partner doing what he is best fitted for.

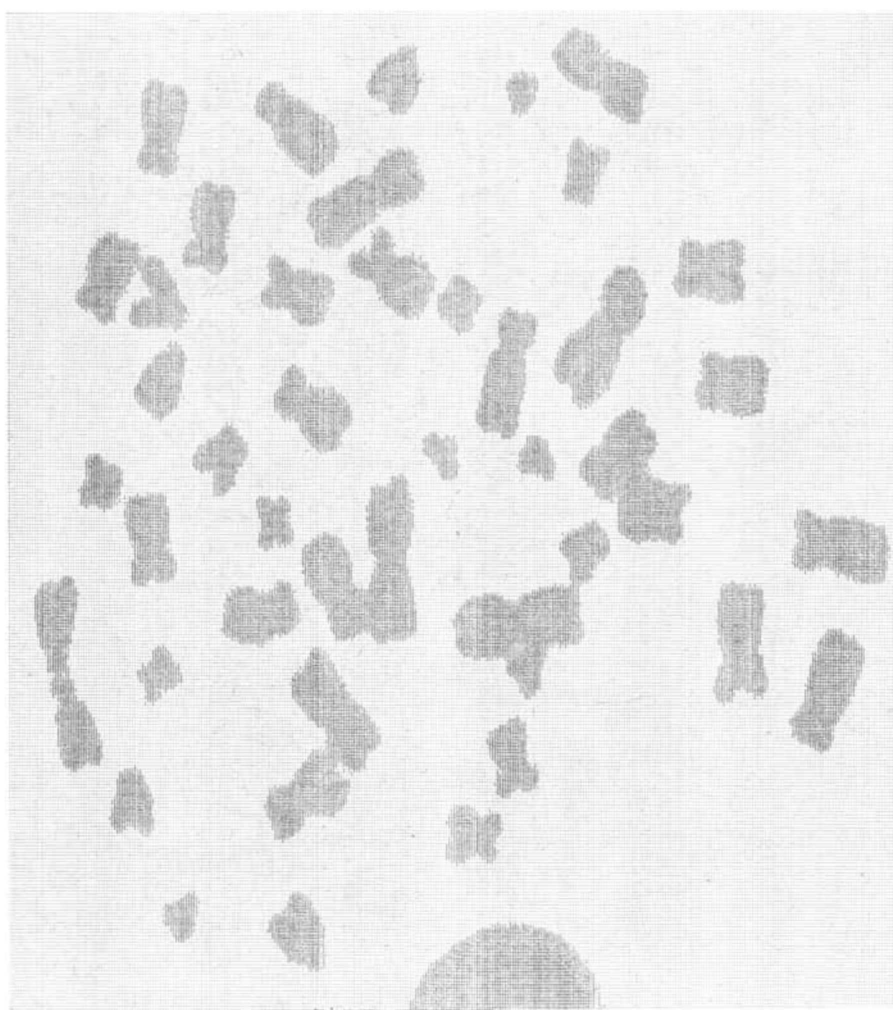
Even more exciting, once the details of the interactions are known theoretically, the X-ray diffraction pattern of the molecule can be calculated and compared with the original observations to remove whatever doubts about the structure are left by ambiguities encountered when going in the other direction. This closing of the circle verifies not only the calculation of molecular structure but also the theoretical edifice that provided the details of molecular interactions.

In this example the computer clearly mimics the molecule according to a script supplied by underlying physical and chemical theory. The computer represents the molecule with a sufficient degree of structural detail to make plausible a metaphorical identification of the computer with the molecule. The metaphor loses its force as we approach details of atomic structure, and the submodels that account for atomic behavior are in this case merely functional.

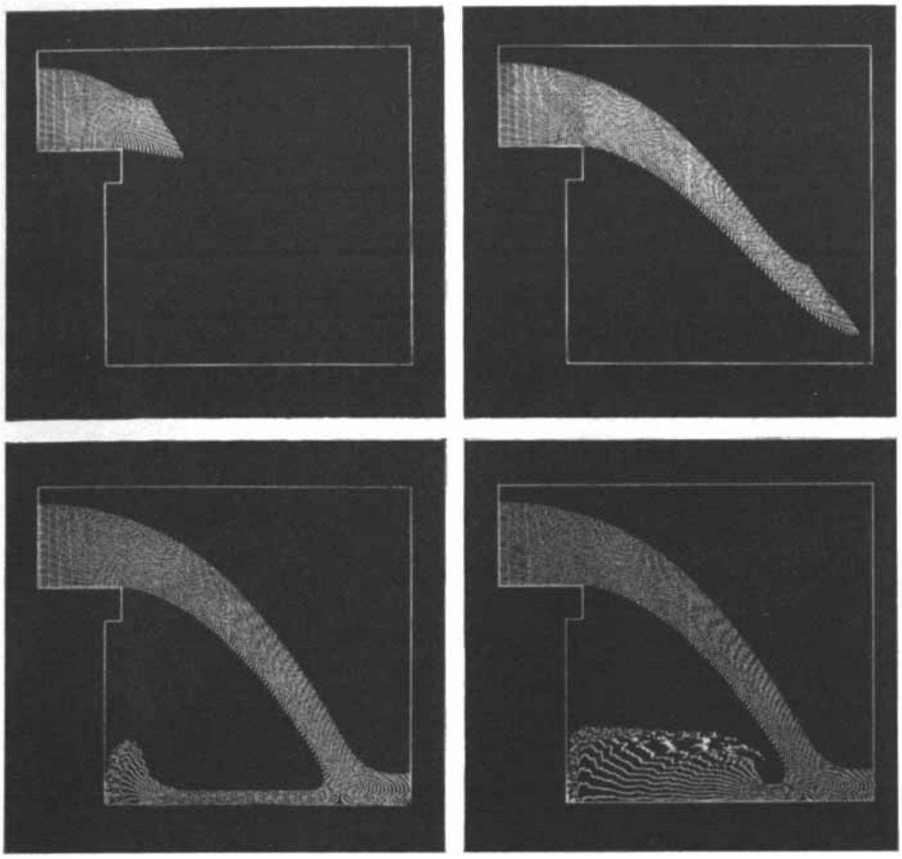
The remarkable immediacy and clarity of the confrontation of acted-out theory and experiment shown in the preceding example is by no means an isolated phenomenon. Similar techniques are emerging in chemistry [see "Computer Experiments in Chemistry," by Don L. Bunker; SCIENTIFIC AMERICAN, July, 1964], in hydrodynamics [see "Computer Experiments in Fluid Dynamics," by Francis H. Harlow and Jacob E. Fromm; SCIENTIFIC AMERICAN, March, 1965] and in other branches of science. It is noteworthy, as Don L. Bunker has pointed out, that computers used in this way, far from reducing the scientist to a passive bystander, reinforce the need for the creative human element in experimental science, if only because witless calculation is likely to be so voluminous as to be beyond the power of even the fastest computer. Human judgment and intuition must be injected at every stage to guide the computer in its search for a solution. Painstaking routine work will be less and less useful for making a scientific reputation, because such "horse work" can be reduced to a computer program. All that is left for the scientist to contribute is a creative imagination. In this sense scientists are subject to techno-







CHROMOSOME ANALYSIS BY COMPUTER makes it possible to examine automatically large numbers of cells for chromosome abnormalities. A photomicrograph of a complement of human chromosomes is shown at top left. An image of the photomicrograph is provided by the grid of numerals in computer print-out at right. Enlargement of a single chromosome appears at bottom left. Print-outs were made with a scanning device called FIDAC and an IBM 7094 computer at the National Biomedical Research Foundation.



SIMULATED WATERFALL spills over the edge of a cliff and splashes into a pool in this computer experiment performed by John P. Shannon at the Los Alamos Scientific Laboratory as part of a general study of dynamic behavior of fluids with the aid of numerical models.

logical unemployment, just like anyone else.

In the "softer" emerging sciences such as psychology and linguistics the excitement and speculation about the future promise of the computer both as instrument and as actor tend to be even stronger than in the physical sciences, although solid accomplishments still are far fewer.

From the time modern computers were born the myth of the "giant brain" was fed by the obvious fact that they could calculate and also by active speculation about their ability to translate from one language into another, play chess, compose music, prove theorems and so on. That such activities were hitherto seen as peculiar to man and to no other species and certainly to no machine lent particular force to the myth. This myth (as expressed, for example, in *New Yorker* cartoons) is now deeply rooted as the popular image of the computer.

The myth rests in part on gross misinterpretation of the nature of a functional model. In the early 1950's, when speculation about whether or not computers can think was at the height of fashion, the British mathematician A. M. Turing proposed the following experiment as a test. Imagine an experimenter communicating by teletype with each of two rooms (or black boxes), one containing a man, the other a computer. If after exchanging an appropriate series of messages with each room the experimenter is unable to tell which holds the man and which the computer, the computer might be said to be thinking. Since the situation is symmetrical, one could equally well conclude that the man is computing. Whatever the decision, such an experiment demonstrates at most a more or less limited functional similarity between the two black boxes, because it is hardly designed to reveal structural details. With the realization that the analogy is only functional, this approach to the computer as a model, or emulator, of man loses both mystery and appeal; in its most naïve form it is pursued today only by a dwindling lunatic fringe, although it remains in the consciousness of the public.

In a more sophisticated vein attempts continue toward devising computer systems less dependent on detailed prior instructions and better able to approach problem-solving with something akin to human independence and intelligence. Whether or not such systems, if they are achieved, should have anything like the structure of a human brain is as relevant a question as whether or not flying machines should flap their wings like birds. This problem of artificial intelligence is the subject of speculative research described in the article by Marvin L. Minsky beginning on page 246. Once the cloud of misapplied functional analogy is dispelled the real promise of using the computer as an animated structural model remains.

Mathematics has so far made relatively few inroads in either linguistics or psychology, although there are now some rather beautiful mathematical theories of language. The scope of these theories is generally limited to syntax (the description of the order and formal relations among words in a sentence). Based as they are on logic and algebra, rather than on the now more familiar calculus, these theories do not lend themselves readily to symbolic calculation of the form to which mathematicians and natural scientists have become accustomed. "Calculations" based on such theories must generally be done by computer. Indeed, in their early form some of these theories were expressed only as computer programs; others still are and may remain so. In such cases the language of programs is the language of science; the program is the original and only script, not just a translation from mathematics.

Early claims that computers could translate languages were vastly exaggerated; even today no finished translation can be produced by machine without human intervention, although machine-aided translation is technically possible. Considerable progress has been made, however, in using computers to manipulate languages, both vernaculars and programming languages. Grammars called phrase-structure grammars and transformational grammars supply the theoretical backdrop for this activity. These grammars describe sentences as they are generated from an initial symbol (say S for sentence) by applying rewrite rules followed (if the grammar is transformational) by applying transformation rules. For example, the rewrite rule $S \rightarrow SuPr$, where *Su* can be thought of as standing for subject and *Pr* as standing for predicate, yields the string *SuPr* when it is applied to the initial symbol S. By adding the rules $Su \rightarrow John$ and $Pr \rightarrow sleeps$ one can turn this string into the sentence "John sleeps." Transformations can then be applied in order to turn, for example, the active sentence "John

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followed the girl" into the passive one "The girl was followed by John."

Under the direction of Susumu Kuno and myself a research group at Harvard has developed, over the past few years, techniques for inverting this generation process in order to go from a sentence as it occurs in a text to a description of its structure or, equivalently, to a description of how it might have been generated by the rules of the grammar. Consider the simple sentence "Time flies like an arrow." To find out which part of this sentence is the subject, which part the predicate and so on, a typical program first looks up each word in a dictionary. The entry for "flies" would show that this word might serve either as a plural noun denoting an annoying domestic insect or as a verb denoting locomotion through the air by an agent represented by a subject in the third person singular.

The specific function of a word in a particular context can be found only by checking how the word relates to other words in the sentence, hence the serious problem of determining which of the many combinations of possible functions do in fact fit together as a legitimate sentence structure. This problem has been solved essentially by trying all possibilities and rejecting those that do not fit, although powerful tests suggested by theory and intuition can be applied to eliminate entire classes of possibilities at one fell swoop, thereby bringing the process within the realm of practicality.

A grammar that pretends to describe English at all accurately must yield a structure for "Time flies like an arrow" in which "time" is the subject of the verb "flies" and "like an arrow" is an adverbial phrase modifying the verb. "Time" can also serve attributively, however, as in "time bomb," and "flies" of course can serve as a noun. Together with "like" interpreted as a verb, this yields a structure that becomes obvious only if one thinks of a kind of flies called "time flies," which happen to like an arrow, perhaps as a meal. Moreover, "time" as an imperative verb with "flies" as a noun also yields a structure that makes sense as an order to someone to take out his stopwatch and time flies with great dispatch, or like an arrow.

A little thought suggests many minor modifications of the grammar sufficient to rule out such fantasies. Unfortunately too much is then lost. A point can be made that the structures are legitimate even if the sentences are meaningless. It is, after all, only an accident of nature, or for that matter merely of nomenclature, that there is no species of flies called "time flies." Worse yet, anything ruling out the nonexisting species of time flies will also rule out the identical but legitimate structure of "Fruit flies like a banana."

Still more confusing, the latter sentence itself is given an anomalous structure, namely that which is quite sensible for "Time flies. . ." but which is nonsensical here since we know quite well that fruit in general does not fly

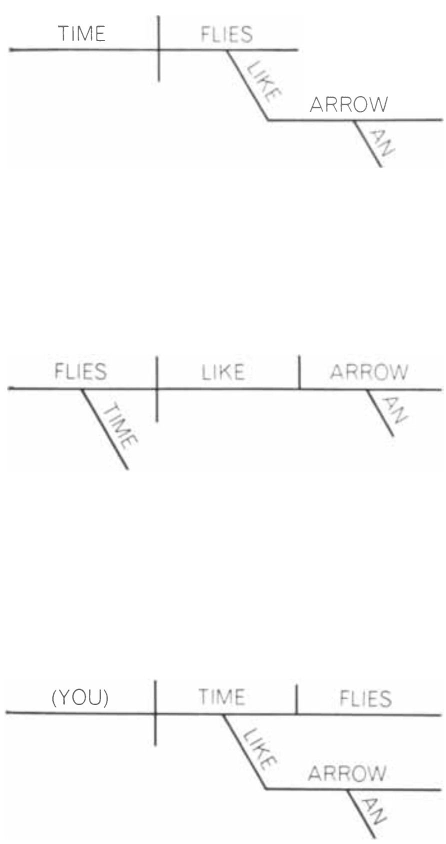
```
***** ANALYSIS NUMBER  1       SENTENCE NUMBER  000001                  CORPUS NUMBER
ENGLISH   SENTENCE STRUCTURE   SWC    SWC MNEMONIC    SYNTACTIC ROLE             RL NUM  PREDICTION POOL
                                                                                         SE
TIME      1S                   NOUS   NOUN 1          SUBJECT OF PREDICATE VERB  SENNNO
                                                                                         PD VSA
FLIES     1V                   VI1S   COMPLETE VI     PREDICATE VERB             VXVI10
                                                                                         PD
LIKE      1VPR                 PRE    PREPOSITION     PREPOSITION                PDPREO
                                                                                         PD NQG
AN        1VPOA                ART    PRO-ADJECTIVE   OBJECT OF PREPOSITION      NQAAAO
                                                                                         PD N5G
ARROW     1VPO                 NOUS   NOUN 1          OBJECT OF PREPOSITION      N5MMMO
                                                                                         PD
.         1.                   PRD    PERIOD          END OF SENTENCE            PDPRDO
-----------------------------------------------------------------------------------------------------

***** ANALYSIS NUMBER  2       SENTENCE NUMBER  000001                  CORPUS NUMBER
ENGLISH   SENTENCE STRUCTURE   SWC    SWC MNEMONIC    SYNTACTIC ROLE             RL NUM  PREDICTION POOL
                                                                                         SE
TIME      1SA                  NOUS   NOUN 1          SUBJECT OF PREDICATE VERB  SENOUO
                                                                                         PD VZA7ZA
FLIES     1S                   NOUP   NOUN 1          SUBJECT OF PREDICATE VERB  7XMMMO
                                                                                         PD VPA
LIKE      1V                   VT1P   NOUN-OBJECT VT  PREDICATE VERB             VXVT11
                                                                                         PD N2A
AN        1OA                  ART    PRO-ADJECTIVE   OBJECT OF PREDICATE VERB   N2AAAO
                                                                                         PD N5A
ARROW     1O                   NOUS   NOUN 1          OBJECT OF PREDICATE VERB   N5MMMO
                                                                                         PD
.         1.                   PRD    PERIOD          END OF SENTENCE            PDPRDO
-----------------------------------------------------------------------------------------------------

***** ANALYSIS NUMBER  3       SENTENCE NUMBER  000001                  CORPUS NUMBER
ENGLISH   SENTENCE STRUCTURE   SWC    SWC MNEMONIC    SYNTACTIC ROLE        RL NUM PREDICTION POOL
                                                                                         SE
TIME      3V                   IT1    INFINITE VT1    IMPERATIVE VERB            SEIT10
                                                                                         PD N2B
FLIES     3O                   NOUP   NOUN 1          OBJECT OF IMPERATIVE VERB  N2NNNO
                                                                                         PD
LIKE      3OPR                 PRE    PREPOSITION     PREPOSITION                PDPREO
                                                                                         PD NQG
AN        3OPOA                ART    PRO-ADJECTIVE   OBJECT OF PREPOSITION      NQAAAO
                                                                                         PD N5G
ARROW     3OPO                 NOUS   NOUN 1          OBJECT OF PREPOSITION      N5MMMO
                                                                                         PD
.         3.                   PRD    PERIOD          END OF SENTENCE            PDPRDO
-----------------------------------------------------------------------------------------------------
```

SYNTACTIC ANALYSIS BY COMPUTER of the sentence "Time flies like an arrow" yields three different structural interpretations, which are represented here by computer print-out (*left*) and by conventional sentence-structure diagrams (*right*). The first structure is one in which "time" is the subject of the verb "flies" and "like an arrow" is an adverbial phrase modifying the verb (*Analysis Number 1*). "Time" can also serve attributively, however, as in "time bomb," and "flies" of course can serve as a noun. Together with "like" interpreted as a verb, this yields a structure that becomes obvious only if one thinks of a kind of domestic insect called "time flies," which happen to like an arrow, perhaps as a meal (*2*). Moreover, "time" as an imperative verb with "flies" as a noun also yields a

and that when it does, it flies like maple seeds, not like bananas.

A theory of syntax alone can help no further. Semantics, the all too nebulous notion of what a sentence means, must be invoked to choose among the three structures syntax accepts for "Time flies like an arrow." No techniques now known can deal effectively with semantic problems of this kind. Research in the field is continuing in the hope that some form of man-machine interaction can yield both practical results and further insight into the deepening mystery of natural language. We do not yet know how people understand language, and our machine procedures barely do child's work in an extraordinarily cumbersome way.

The outlook is brighter for man-made programming languages. Since these can be defined almost at will, it is generally possible to reduce ambiguity and to systematize semantics well enough for practical purposes, although numer-

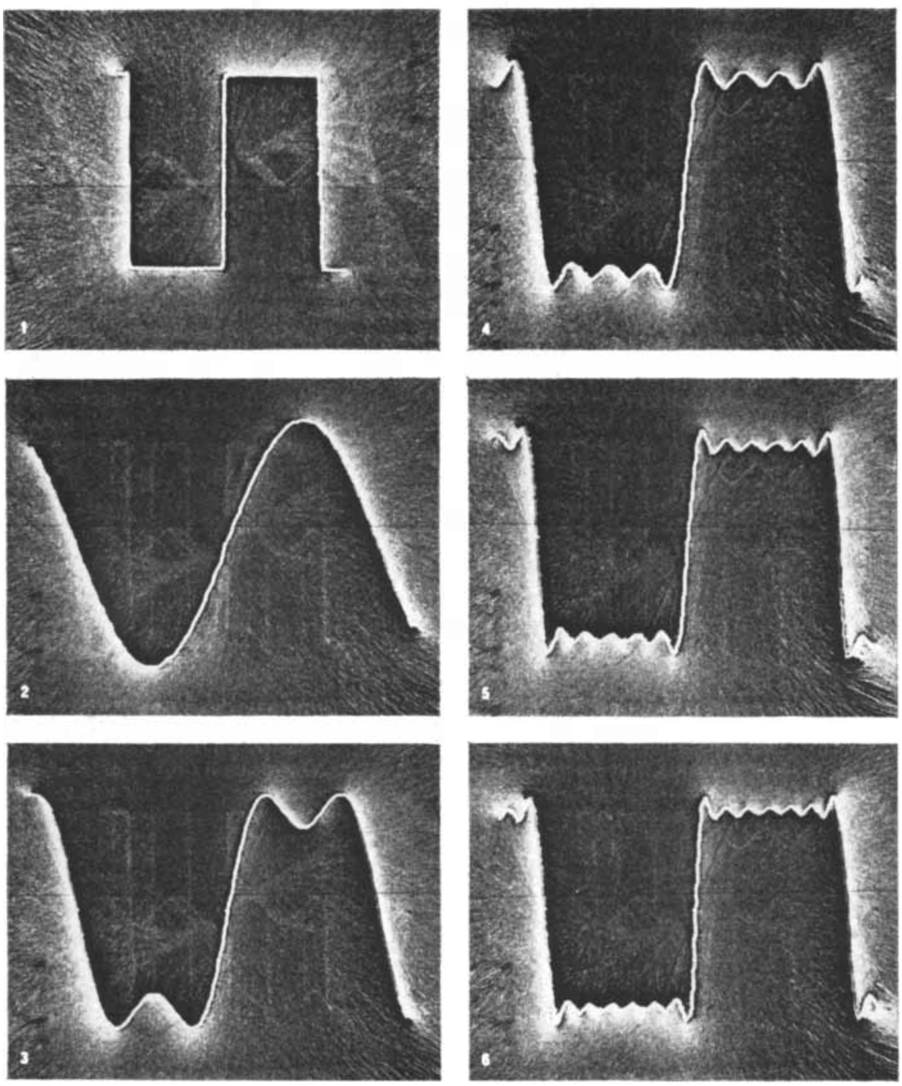


structure that makes sense as an order to someone to take out his stopwatch and time flies with great dispatch, or like an arrow (3). No computer techniques now known can deal effectively with semantic problems of this kind, but research in the field is continuing.

ous challenging theoretical problems remain. The computer is also growing in power as an instrument of routine language data processing. Concordances, now easily made by machine, supply scholars in the humanities and social sciences with tabular displays of the location and context of key words in both sacred and profane texts.

Psychologists have used programming languages to write scripts for a variety of structural models of human behavior. These are no more mysterious than scripts for the orbit of Neptune or the structure of hemoglobin. The psychological models differ from the physical ones only in their subject and their original language. Convincing empirical corroboration of the validity of these models is still lacking, and the field has suffered from exaggerated early claims and recurrent confusion between the functional and the structural aspects of theory. Psychology and the study of artificial intelligence are both concerned with intelligent behavior, but otherwise they are not necessarily related except to the extent that metaphors borrowed from one discipline may be stimulating to the other.

In actuality it is the languages, not the scripts, that are today the really valuable products of the attempts at computer modeling of human behavior. Several languages, notably John McCarthy's LISP, have proved invaluable as tools for general research on symbol manipulation. Research on natural-language data processing, theorem-proving, algebraic manipulation and graphical display draws heavily on such languages. Nevertheless, the computer as instrument is rapidly making a useful place for itself in the psychology laboratory. Bread-and-butter applications include the administration, monitoring and evaluation of tests of human or animal subjects in studies of perception and learning.



PROBLEM IN MATHEMATICS illustrates the author's experimental use in Harvard classrooms of a keyboard-and-display system developed by Glen Culler of the University of California at Santa Barbara. It is well known that any periodic function (in this example the square wave at top left) can be approximated by the sum of a series of terms that oscillate harmonically, converging on the curve of the function. Culler's apparatus makes possible quick intuitive exploration of the nature of this approximation. The other curves show the effect of increasing the number of terms in the partial sum of the series. The spikes near the corners of the square wave are caused by nonuniform convergence near a discontinuity.

The business of science, both in principle and in practice, is inextricably involved in the business of education, particularly on the university level. The paradigm of the computer as instrument and as actor, although described in terms of research, seems to apply to instruction as well. Because on-line, time-shared systems are still experimental and expensive, especially with graphical display facilities, their use for instruction lags somewhat behind their use for research.

Hopes for computers in education at the elementary or secondary level are described in the article by Patrick Suppes beginning on page 206. My own current exploration of the potential value of technological aids to creative thought focuses rather on the undergraduate or graduate student and on the transition from learning in the classroom to learning when practicing a profession.

The desire to keep labor within reasonable bounds generally leads to oversimplified and superficial experiments in student laboratories. Where the observation and intelligent interpretation of a variety of significant phenomena are the primary objectives of a laboratory exercise, using a transparent computer should reduce unnecessary drudgery to the point where judgment and interpretation, even of realistic experiments, can prevail.

The transparent computer also promises to be effective as a kind of animated blackboard. This hardly implies the disappearance of chalk, films or books. The computer merely adds another powerful and versatile tool to the teacher's kit. In fact, where repetition or polish is necessary, the computer itself can serve to make films or equivalent visual recordings. We have found that whereas films cannot be interrupted or altered, a recorded computer sequence can easily be stopped in response to a student's question; the lecturer can then explore alternatives by returning either to the informal direct use of the computer or to the conventional blackboard. The prerecorded sequence can then be resumed.

Best of all, there need be no distinc-

tion between the classroom tool and that available to students for homework assignments, laboratory calculations or individual research projects. The transition from classroom to life therefore promises to be made smoother. Since computers are not yet either as transparent or as cheap as one might wish, many problems of technique and finance remain to be faced. In any case, no panacea has been found for education's ills, only a richer range of choices to be made.

An example based on our experimental use in Harvard classrooms of a keyboard-and-display system developed by Glen Culler at the University of California at Santa Barbara will illustrate both the promise and the problems. Since the static printed page cannot adequately portray the effect of dynamic display, the problems may be more evident than the promise. The topic chosen is mathematical in nature, since such problems are best suited for the equipment currently available. The objective is to develop a natural and perspicuous presentation of topics traditionally reserved for more advanced treatment, to develop others in greater depth than conventional methods allow and to stimulate the student's intuition and his resourcefulness in solving problems. The objective is not to eliminate theory and rigor in favor of witless calculation, but rather to restore the close link between theory and calculation that characterized mathematics before the advent of rigor late in the 19th century led to the aberrant but currently fashionable split between pure and applied mathematics.

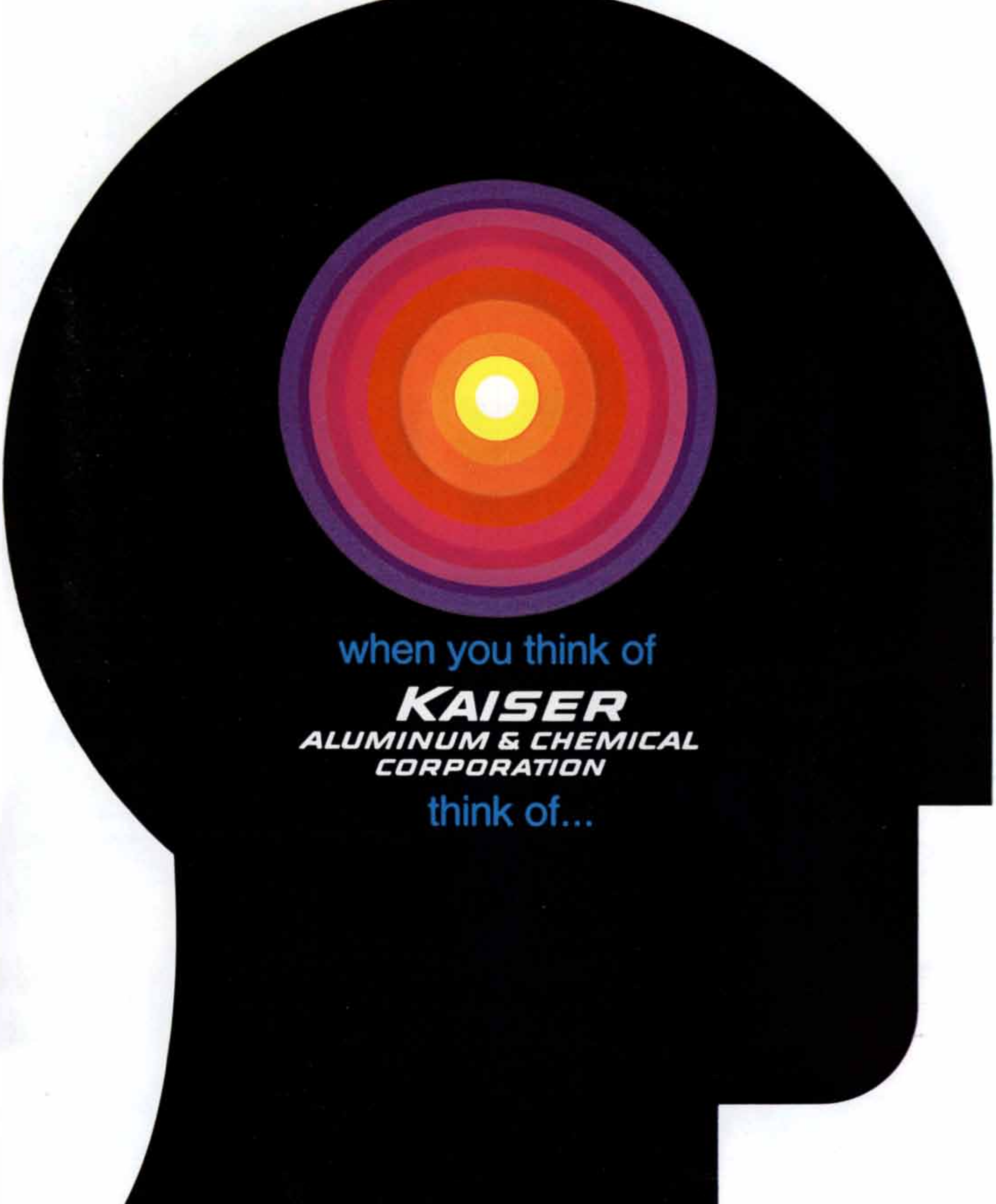
It is well known that any periodic function can be approximated by the sum of a series of terms that oscillate harmonically, converging on the curve of the function. Culler's apparatus makes possible quick intuitive exploration of the nature of this approximation. Consider, for example, the square wave shown at top left in the illustration on page 170. The accompanying computer-generated curves show the effect of increasing the number of terms in the partial sum of the series. The spikes near the corners of the square wave are caused by nonuniform convergence near a discontinuity. For the pure mathematician this demonstration can motivate a more formal treatment of nonuniform convergence. For the engineer the phenomenon can be clarified by displaying the components of the approximation in such a way as to make it obvious intuitively why the spikes occur. In principle the instructor, or an interested student on his own, could follow up such a demonstration by modeling the effect of a linear circuit element, say a resistor or a simple amplifier, on a square wave, on its individual components and on their sum.

At present any concurrent formal algebraic manipulations require pencil or chalk. Current progress toward machine-aided algebraic manipulation raises the exciting possibility that machines will eventually help with both symbolic and numerical manipulation and with easy transitions between these two modes of expression. Working in both modes simultaneously or in whatever combination rigor and intuition demand would profoundly affect the thought of pure and applied mathematicians alike.

Other types of teaching experiment can be conducted by building an appropriate structural model into the computer. One might assume the structure and examine its behavior, as is frequently done in management games, or one might treat only the behavior as observable, leaving the model to be determined as an exercise in theory-building. As paradigms are developed by research in some area, these paradigms could then be applied as well to teaching in that area. It will be interesting, for example, to experiment with the teaching of a foreign language for which a transformational grammar of the type I described earlier has been implemented on a computer.

It is also interesting to speculate on the use of on-line computers as tools for the investigation of the psychology of learning and problem-solving. Experiments in this area have been difficult, contrived and unrealistic. When the interactive computer serves as a problem-solving tool, it is also easily adapted to record information about problem-solving behavior. Here again the problem will not be the collection of data but rather devising appropriate experimental designs, since an hour's problem-solving session at a computer console can accumulate an enormous amount of data.

In short, computers are capable of profoundly affecting science by stretching human reason and intuition, much as telescopes or microscopes extend human vision. I suspect that the ultimate effects of this stretching will be as far-reaching as the effects of the invention of writing. Whether the product is truth or nonsense, however, will depend more on the user than on the tool.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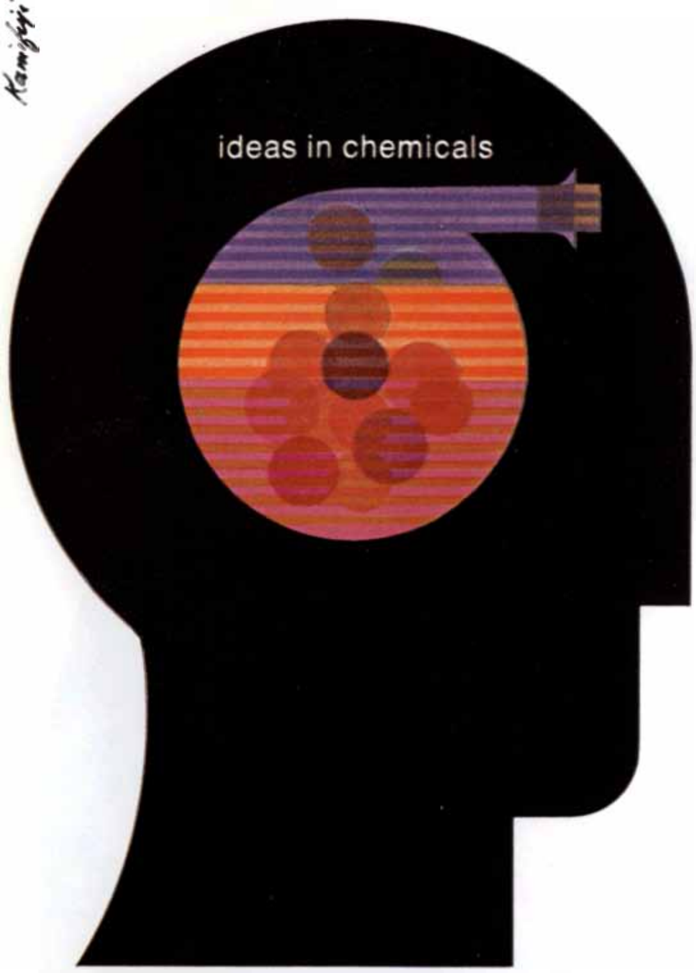
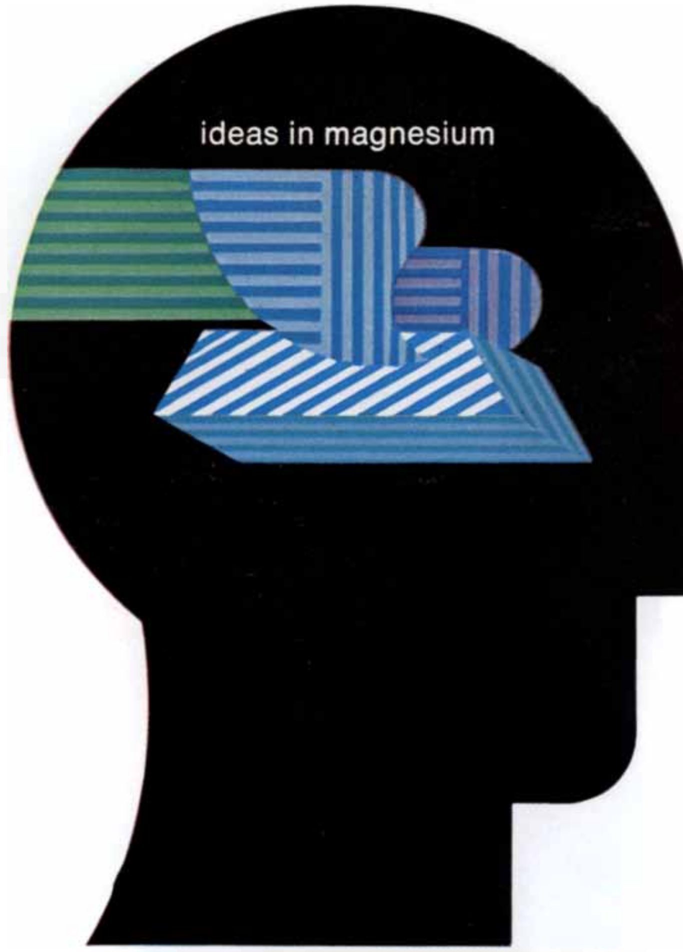
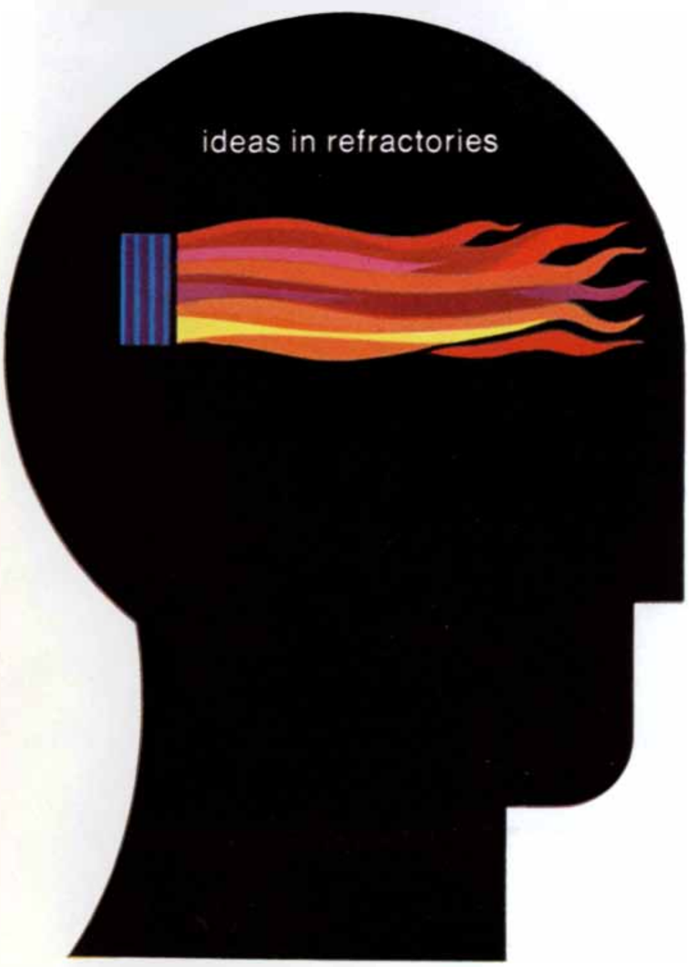
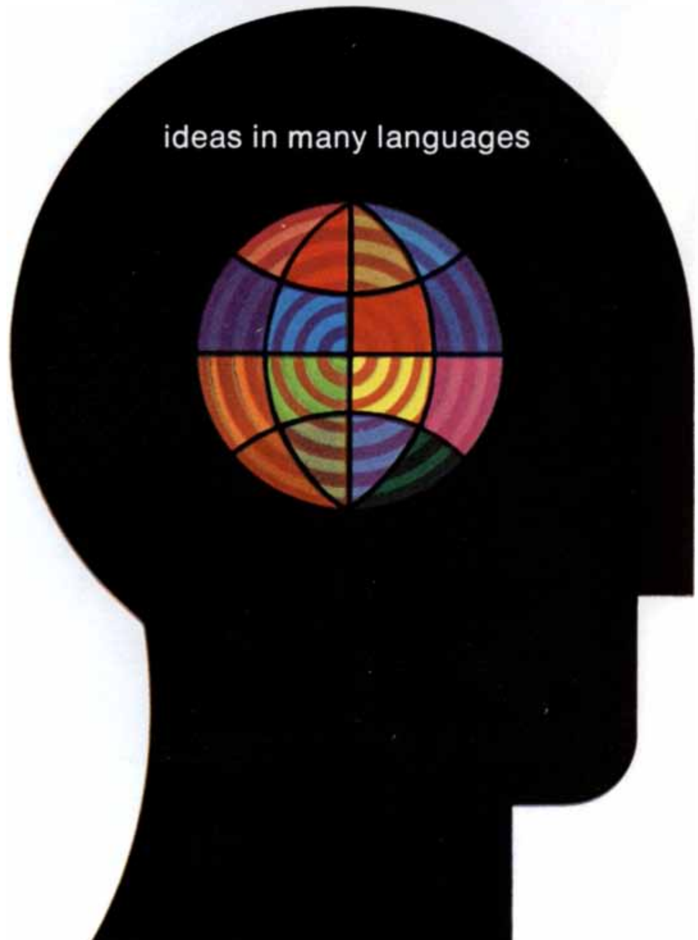
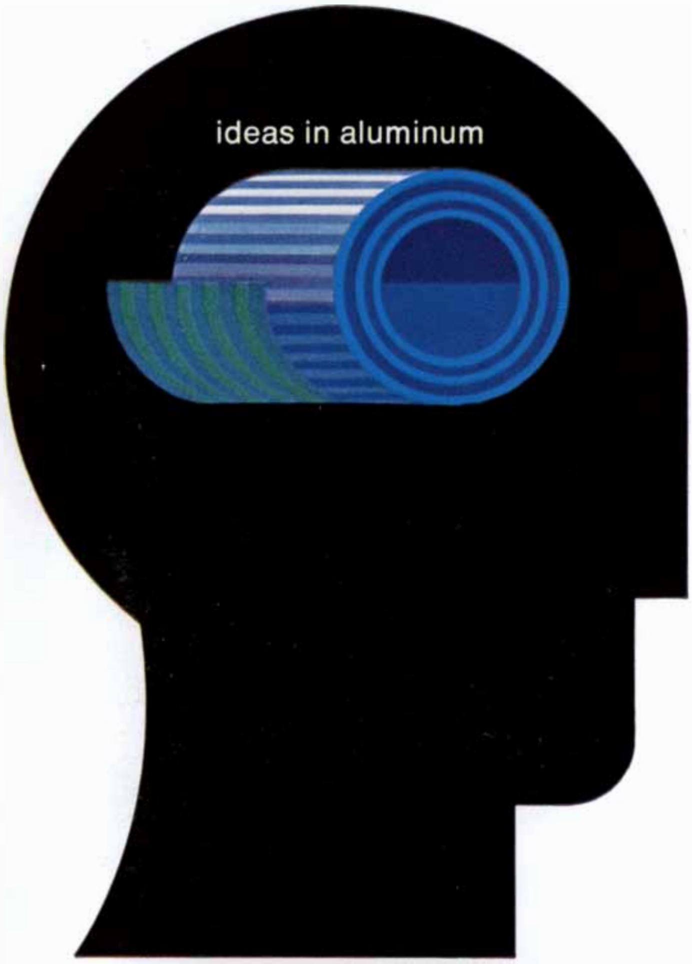
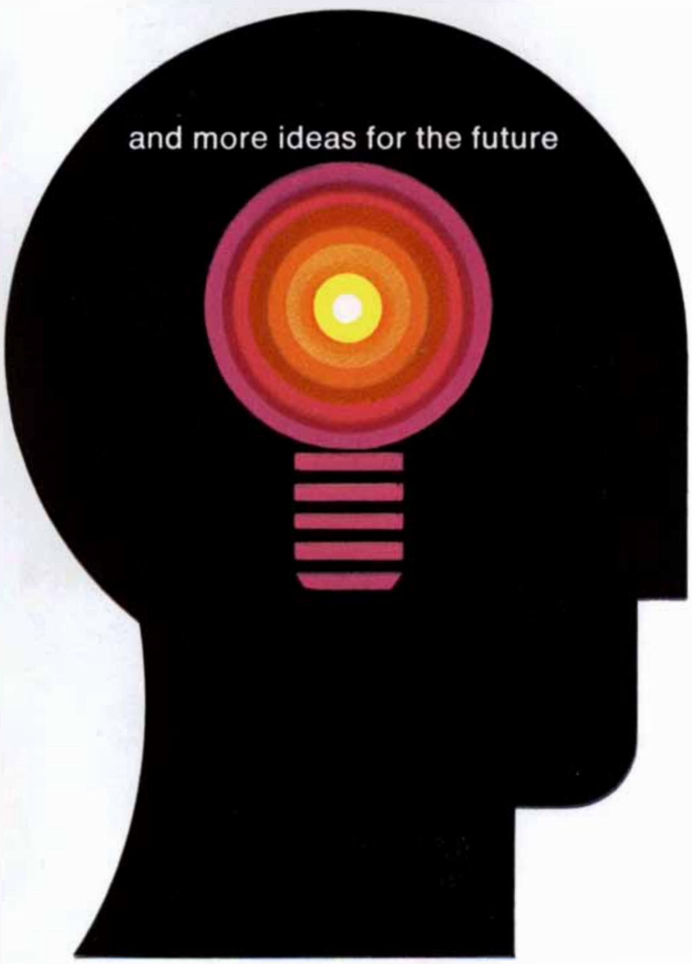

ideas in chemicals


ideas in magnesium


ideas in refractories


ideas in many languages





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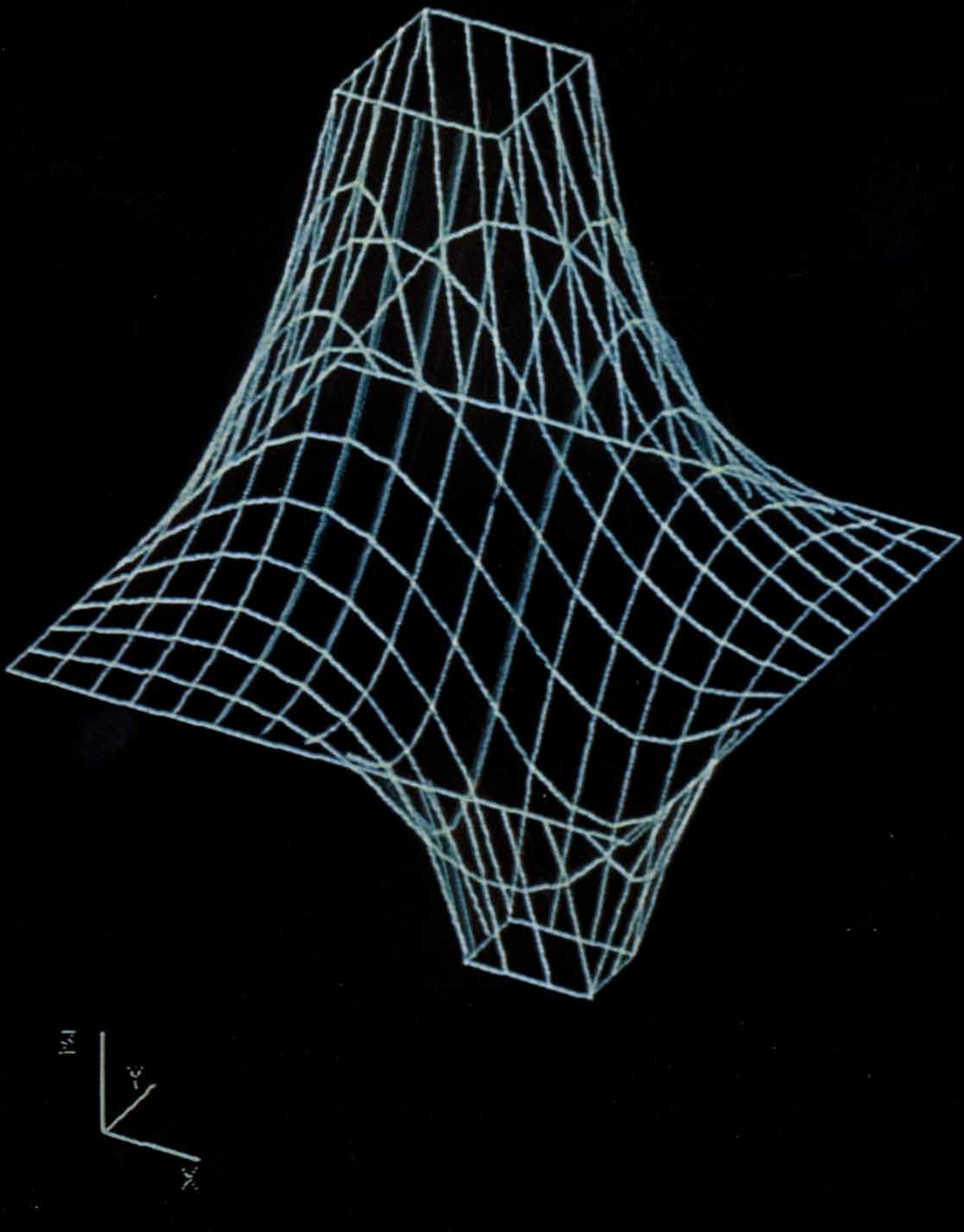

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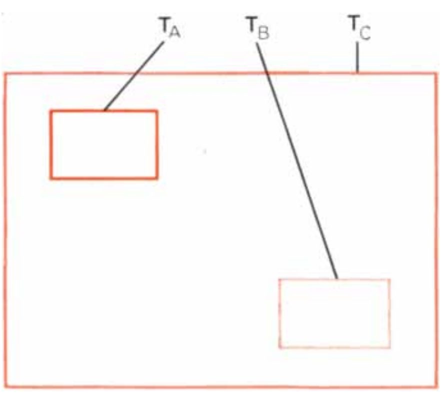
The Uses of Computers in Technology

In most technological applications computers have been used to execute a specific program of instructions. Now they are beginning to fulfill their promise of interacting directly with men in engineering design

by Steven Anson Coons

The uses of computers in technology fall into two categories. One is traditional (if so new a field can be said to have a tradition), the other quite novel. The first category includes the multifarious applications in which the computer carries out a program of instructions with little or no intervention by human beings. This is a powerful way to use an information-processing machine, and it has dominated the early years of the computer era. The second category embraces a new class of applications in which the computer is an active partner of man. I believe that within the next few years this new way of using computers will bring about deep changes in the large segment of technology that might be called "creative engineering."



THE COMPUTER-GENERATED display on the opposite page is a graphical solution of a typical "equilibrium" problem in engineering: to show the heat distribution in a slab. The rectangular slab (*see illustration above*) has two regions whose boundaries are maintained at temperatures (T_A *and* T_B) that are respectively the same amount higher and lower than the temperature (T_C) at which the boundary of the slab itself is maintained. The curves connecting the three rectangles in the display give the heat distribution, with the temperatures indicated by the *z* coordinate. The display was generated on a Project MAC terminal at the Massachusetts Institute of Technology; the computer program was Equilibrium Problem-Solver, designed by Coyt Tillman of M.I.T.

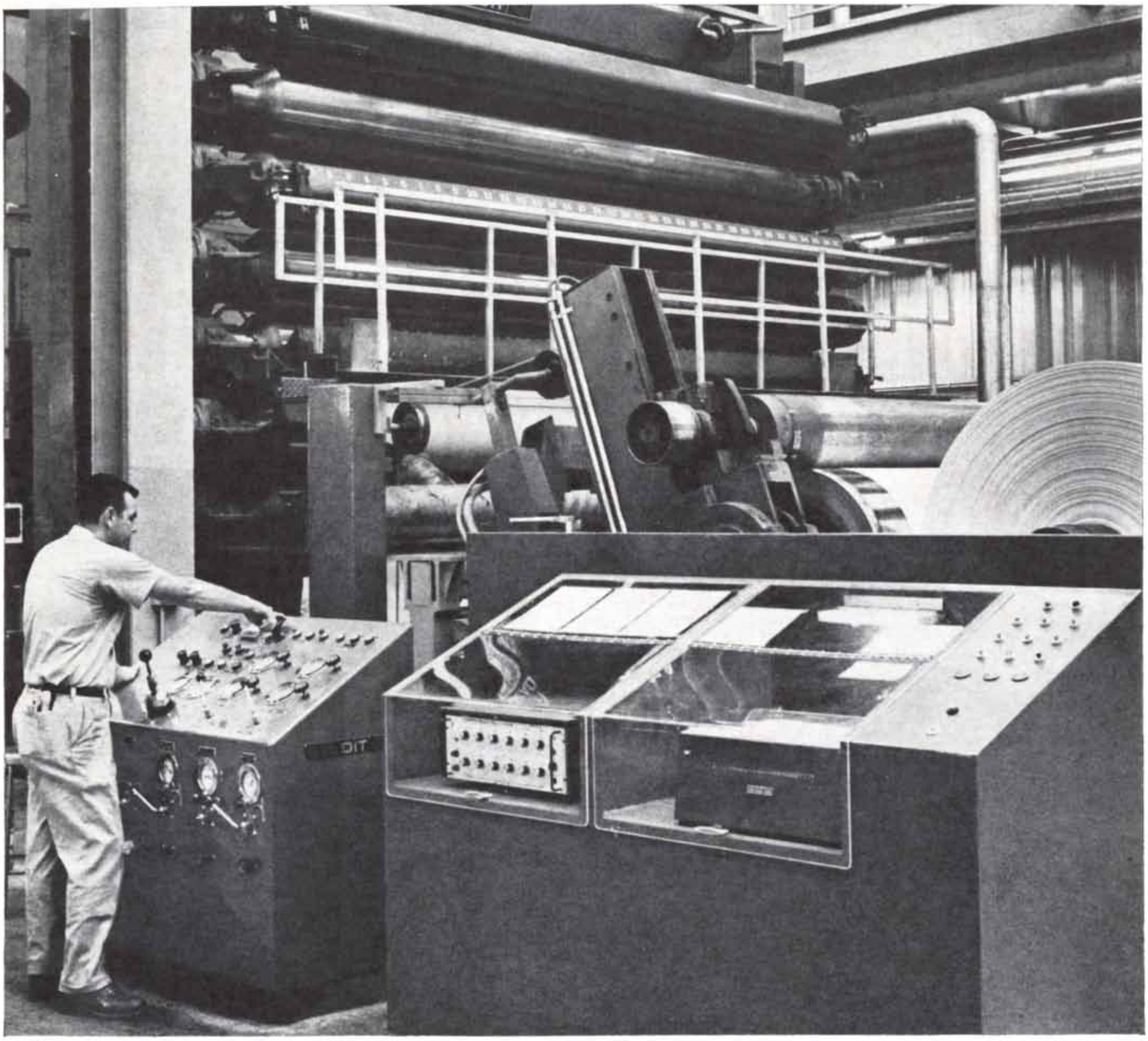
As the computer is traditionally applied to a technological task, it acts as it is told to act. This is not to say that a machine so instructed cannot accomplish impressive tasks. Its program can be quite elaborate—so complex that no human being could follow it in a reasonable length of time (even, in some instances, in an unreasonable length of time). In obeying instructions a computer often deals appropriately with changing circumstances and adjusts to variations in its environment, achieving its purpose by a process so subtle as to give the impression of adaptive intelligence. The machine is nonetheless acting as an automaton. Its behavior, although complex, is mechanical and predictable. Man's ingenuity is applied to presenting the problem or setting up the task; thereafter the machine grinds away at the solution or execution.

This is not the case when the computer and man are linked in what J. C. R. Licklider of the International Business Machines Corporation calls a symbiotic relationship, a relationship in which each can perform the kind of activity for which it is best suited. Man is quite good at inventing and organizing ideas, making associations among apparently unrelated notions, recognizing patterns and stripping away irrelevant detail; he is creative, unpredictable, sometimes capricious, sensitive to human values. The computer is almost exactly what man is not. It is capable of paying undivided attention to unlimited detail; it is immune to distraction, precise and reliable; it can carry out the most intricate and lengthy calculation with ease, without a flaw and in much less than a millionth of the time that would be required by its human counterpart. It is emotionless, or so we suppose. It suffers from neither boredom nor fatigue. It needs to be told only once; thereafter it remembers perfectly until it is told to forget, whereupon it forgets instantly and absolutely.

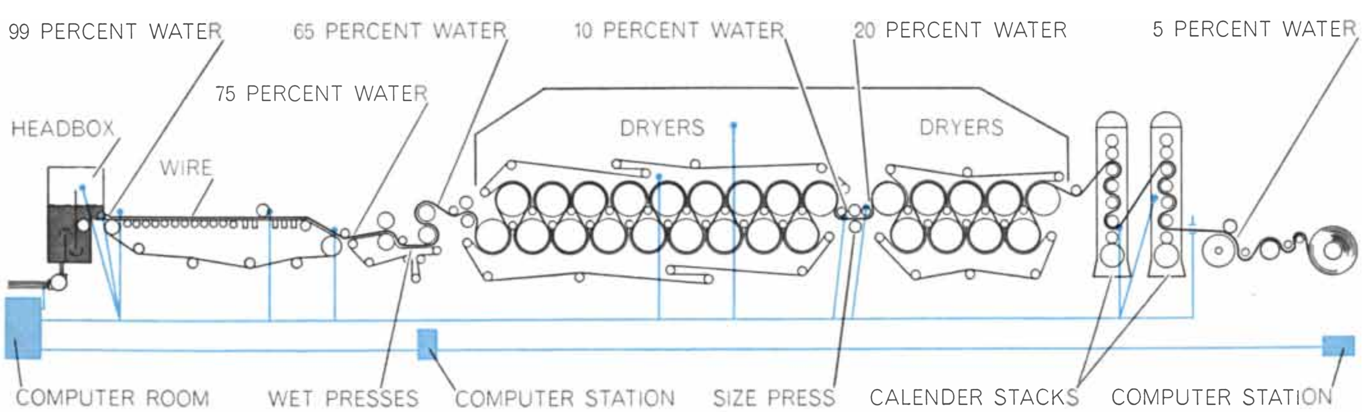
When man and machine work together, the shortcomings of each are compensated by the other, which leaves both partners free to exercise their individual powers in a common enterprise. The potential of such a combination is greater than the sum of its parts.

It was clear when the first electronic computers were being developed that the machines could by their nature deal easily with repetitive calculations. During World War II computers worked out firing tables for artillery. Another early application was the calculation of logarithmic and trigonometric tables to a large number of significant figures. It was startling to find that some of the classic tables that had been calculated "by hand" contained errors that were discovered only after computer calculation. Computers have continued to specialize in bulky calculations, particularly those in which the procedure is either involved and complicated or repetitive.

It soon became apparent, however, that the computer could also maintain quite sophisticated control over its own procedures and could successfully attack problems of a more difficult kind. Specifically, the ability of the computer to compare two numbers and to elect any one of two or three courses of action based on the outcome of the comparison, although simple in principle,



PAPER MACHINE at the Mead Corporation's Kingsport Division in Tennessee has a computer process-control system. The 405-foot-long machine produces rolls of paper up to 16 feet wide at the rate of 2,000 feet per minute. An IBM 1710 control system monitors the process and directly controls one of the important variables, the average "basis weight" of the paper. The remote unit shown here includes a printer (*right*) that brings data to the operator and an input unit through which he communicates with the computer.



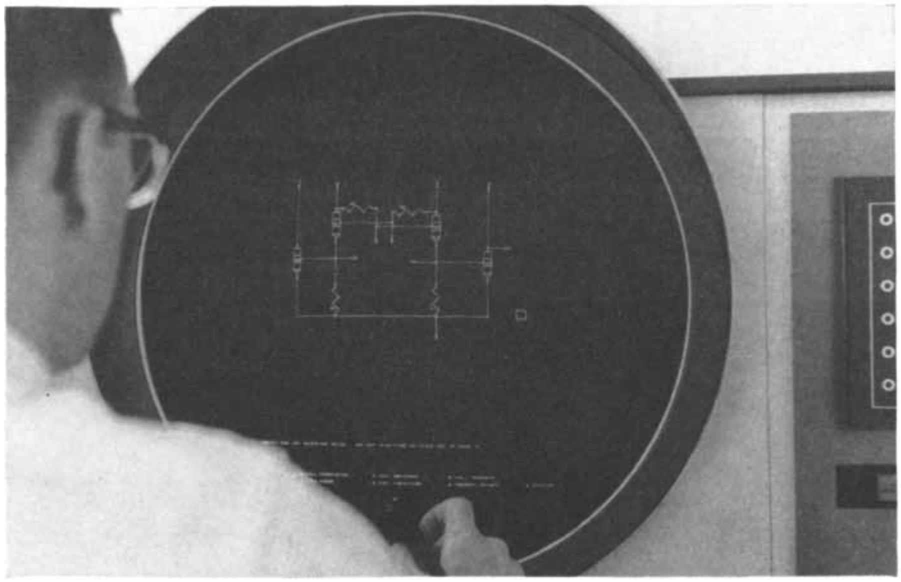
COMPUTER INSTALLATION is shown in color in this simplified schematic diagram with colored dots indicating typical measuring points. A mixture of wood pulp, water and additives emerges from the headbox, is spread on a wire screen and carried through pressing and drying operations. The basis weight is measured by a beta-ray gauge (*right*); the computer reports any variations from the desired standard, warns the operators and computes and initiates corrections in the flow rate of materials at the headbox (*left*).

has led to some sophisticated applications. A computer can in fact be relied on to carry out the most intricate processes in the manipulation and transformation of information, provided that these processes are understood well enough by humans to be described in complete detail to the computer.

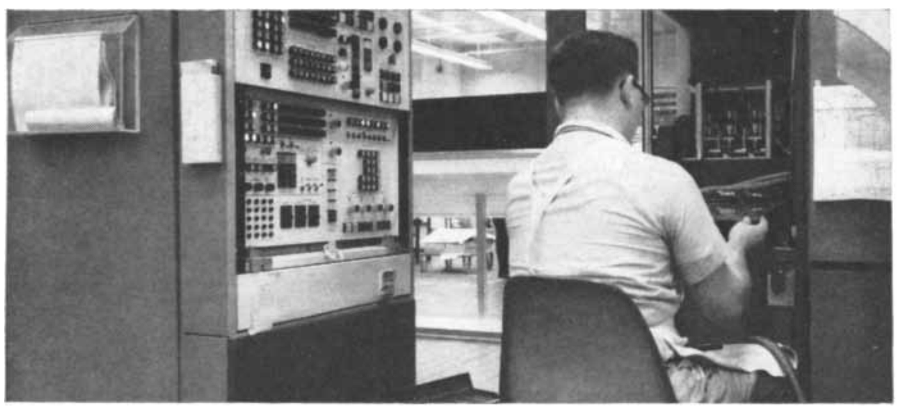
A computer can, for example, control industrial processes. Not all "automated" industrial plants have computer systems and not all computerized plants are equally automatic. It is possible to construct complex control systems based on continuous monitoring and feedback loops without including computers. Sometimes computers are introduced to make calculations and inform a human operator what needs to be done. Moreover, a computer can on its own control an individual subprocess or regulate an important variable in a production line. In some cases (still largely confined to the petroleum and chemical industries) a computer system actually controls the routine operations of the plant.

The control of chemical plants is a good example of an application in which the computer can deal with a large amount of information, monitoring the many variables involved in such a way as to maintain optimum production and quality of product. The variables in a chemical process—temperature, pressure, flow, valve settings, viscosity, color and many others—are interrelated in complicated ways, and usually the relations are highly nonlinear. If two ingredients must flow into a reaction vessel in a certain ratio, and the flow rate of one ingredient is deficient for some reason, it does no good for the computer system to attempt to rectify the deficiency by opening the supply valve wider if the valve is already fully open; instead the computer should take account of the state of affairs and close the valve on the other supply line until the desired ratio of flows is achieved.

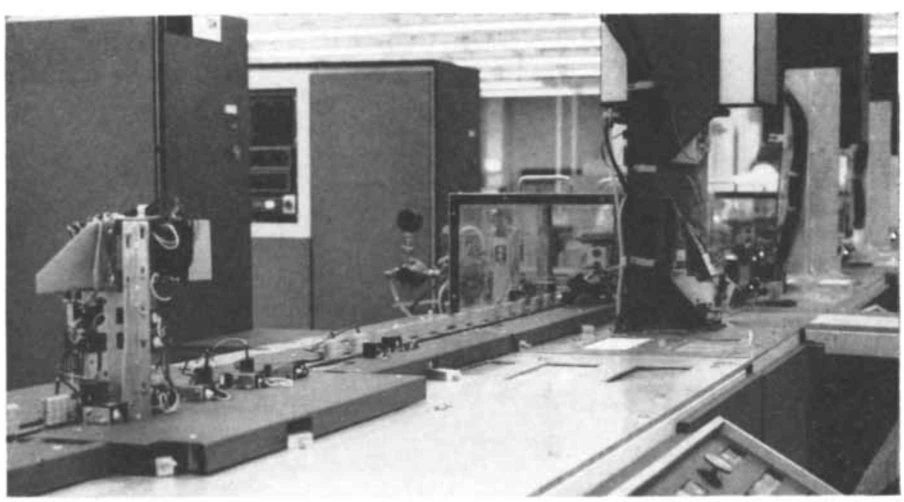
A computer is able to receive information from many measuring stations located at strategic places in the process plant, to perform the necessary calculations and comparisons of these detailed data, to make decisions on how to monitor the control mechanisms and to send commands back to them in such a way as to maintain optimum operation. This capability is highly reliable, and since there is essentially no limit to the complexity of the information with which the computer can deal, industrial engineers can now devise processes so intricate that it would be difficult, if not



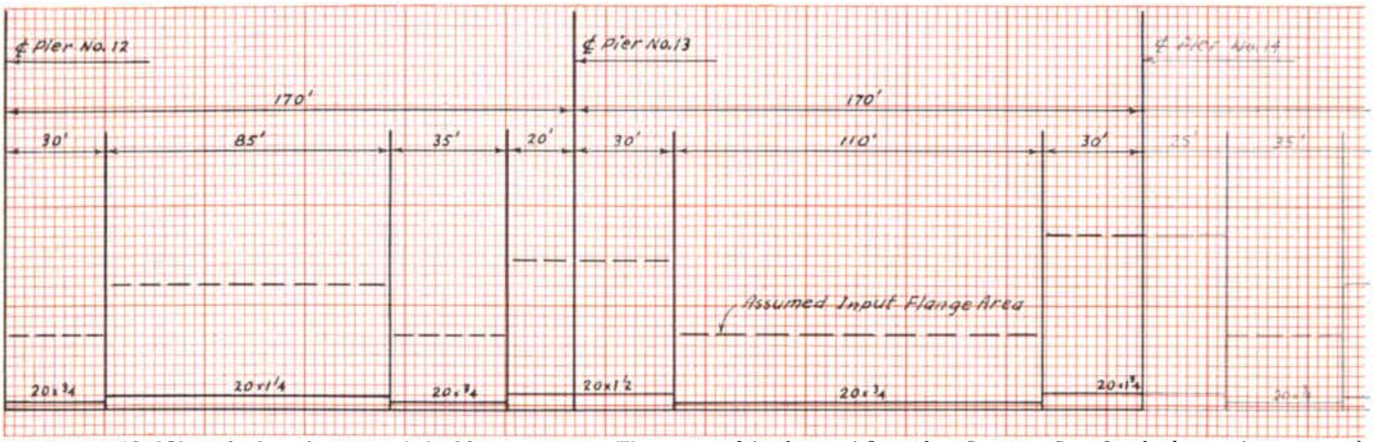
MACHINES MAKE MACHINES in International Business Machines Corporation plants producing System 360 computers. Drawings for circuit modules can be produced with a 1620 computer. The designer draws a schematic circuit diagram (*shown here*) and module layout with a light pen. The computer produces the module design used in manufacturing.



DRILLING MACHINE that produces panels for printed-circuit cards for the System 360 is controlled by a unit (*left*) of a 1710 control system. The 1710, on a time-shared basis, sends instructions to position the 24-spindle drill, which drills 6,000 holes in less than a minute. The computer also controls an electron-beam "hole-tester" that spot-tests diameters.



MICROCIRCUIT ASSEMBLIES for the System 360 move through a computer-controlled final test line. The testing machine, controlled by an IBM 1410 (*left background*), can perform hundreds of different tests for shorts, impedance or logical integrity on each card.

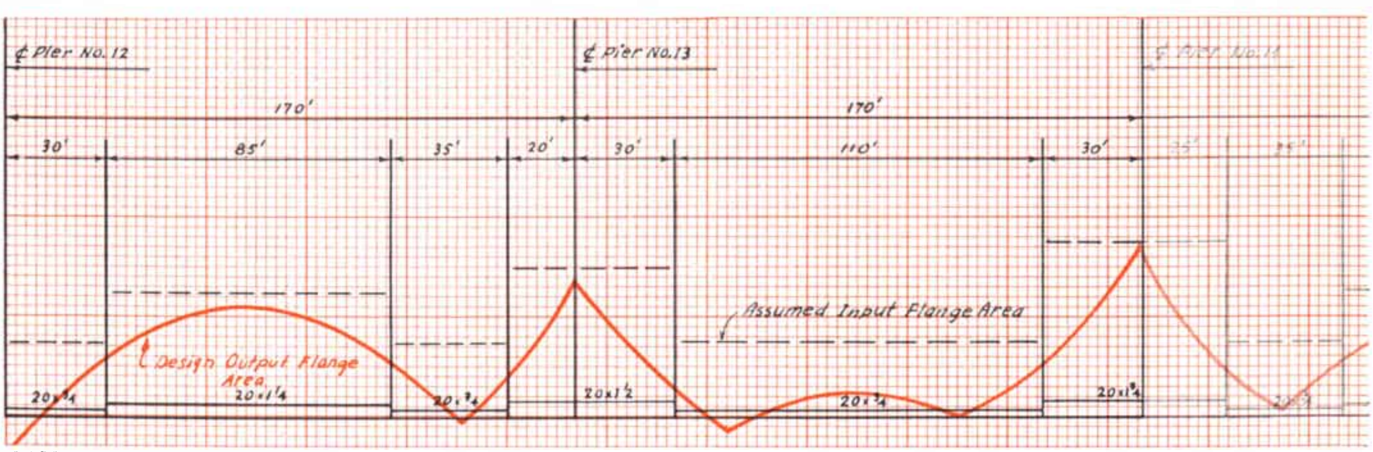


BRIDGE DESIGN can be largely accomplished by a computer. This sequence illustrates the design of two spans of a continuous-plate-girder portion of a bridge designed by Louis Berger & Associates for the New Jersey Turnpike Authority, using the computer system and facilities of Omnidata Services, Inc. On the basis of an assumed design the engineer plots (*broken lines*) estimated cross-sectional areas of the "flanges," or horizontal members of the girder. For example, he assumes 20-by-¾-inch flanges for the first 30-foot segment.

```
1     5      4      0      1.21   0.     0.
170.  1.378  1250.
1     170.   78.    78.
2     30.    20.    .75
2     115.   20.    1.25
2     150.   20.    .75
2     170.   20.    1.50
3     30.    20.    .75
3     115.   20.    1.25
3     150.   20.    .75
3     170.   20.    1.50
4     170.   99999. .5
170.  1.375  1250.
1     170.   78.    78.
2     30.    20.    1.5
2     140.   20.    .75
2     170.   20.    1.75
3     30.    20.    1.5
3     140.   20.    .75
3     170.   20.    1.75
4     170.   99999. .5
```

```
160001000000
NON-COMPOSITE CONTINUOUS BEAM PROGRAM
3 2 20. 27. 0.

     NON-COMPOSITE CONTINUOUS STEEL BEAM DESIGN @ X/10 POINTS

 SPANS          STRESS-1        STRESS-2        STRESS-3
   3               20              27               0

 SPAN
   1

X-POINT        FLANGE-AREA     FLANGE-AREA     FLANGE-AREA

   1            9.5910076       5.4189283
   2           21.283315       14.079896
   3           28.591007       19.493002
   4           31.552546       21.686734
   5           30.198700       20.683885
   6           24.575623       16.518643
   7           14.744853        9.2365921
   8            .85254615      -1.0540062
   9           17.044853       10.940295
  10           39.760238       27.766506

 SPAN
   2

X-POINT        FLANGE-AREA     FLANGE-AREA     FLANGE-AREA

   1           20.775623       13.703828
   2            7.5294692       3.8918626
   3            1.7294692      -.40443361
   4            7.3987000       3.7949965
   5            9.1679307       5.1055379
   6            6.7063923       3.2821760
   7            4.6140846       1.7323185
   8           13.367930        8.2166490
   9           28.206392       19.208102
  10           48.560238       34.285025
STOP
```

INPUT TO COMPUTER (*left*) includes coded specifications (*top*) and estimated flange areas for segments of the assumed girder. The computer calculates stresses on the girder and gives, for two kinds of steel, exact flange areas at 10 points along each span (*right*).



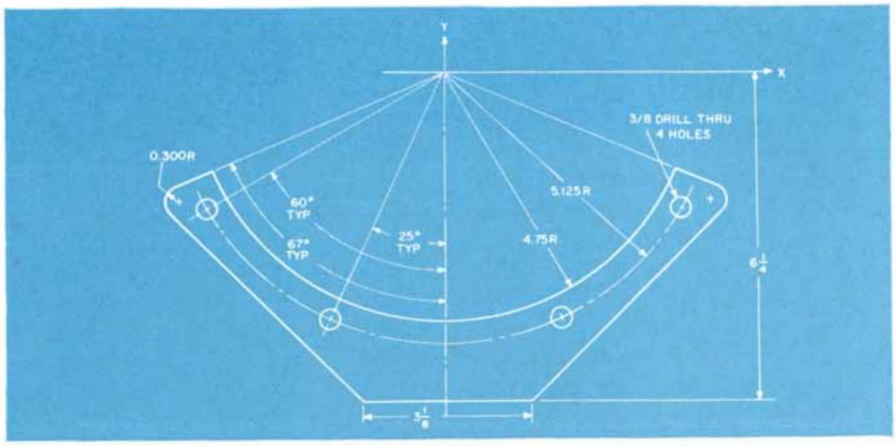
COMPUTED FLANGE AREAS are then plotted (*color*) on the engineer's work sheet. In this case the computer has confirmed the estimated design of the girders, as can be seen here because the colored line falls within the estimated values for the flange areas.

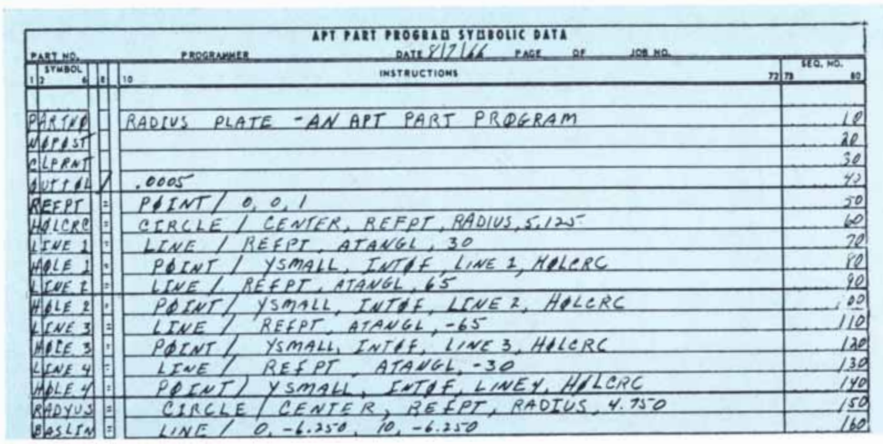
impossible, to control them with human workers.

Another industrial application of computers lies in the numerical control of machine tools. A great many parts of machines are produced by either milling or routing, processes in which a cutting tool moves so as to cut some contoured shape out of sheet metal or heavier stock. In conventional methods this demands the constant attention of a skilled machine operator, particularly if the contour to be formed is irregularly curved. Under the control of a computer the cutter can be made to move in any desired path, and it is in principle no more difficult to produce "sculptured" shapes bounded by complex curved surfaces than it is to produce objects with flat faces. The numerical control of machine tools has enjoyed an extraordinary success because it guarantees the reliability and reproducibility of even the most elaborate shapes. The spoilage due to human error is reduced to the vanishing point, and many parts are now practicable that would be prohibitively expensive to produce if a human operator had to monitor the settings of the machine.

A striking example is the milling of airplane-wing "skins" from slabs of aluminum alloy. For structural reasons these sheet metal skins need to be thicker near the wing roots, where the bending stress is high, than they do near the wing tips, where it is less. For a long time this has been accomplished by assembling an elaborate laminated structure, with sheets of varying thickness fastened together by hundreds of rivets and stiffened by bulkheads and frames. The assembly of such structures is complicated and time-consuming. Now it has been found that much of the wing structure can literally be cut out of solid slabs—tapered thickness, stiffening members and all—at a cost and in a time substantially less than is needed for conventional assembly methods. Wing skins cut from slabs two inches thick, 10 feet wide and 40 feet long are not at all uncommon.

The increasing capabilities of modern computers suggested that a more direct partnership between the machines and their human operators would be effective, and several developments described in other articles in this issue combined to make this possible. First, the languages by which men communicate with computers have evolved rapidly. Language forms have now begun to appear that are much more "problem-

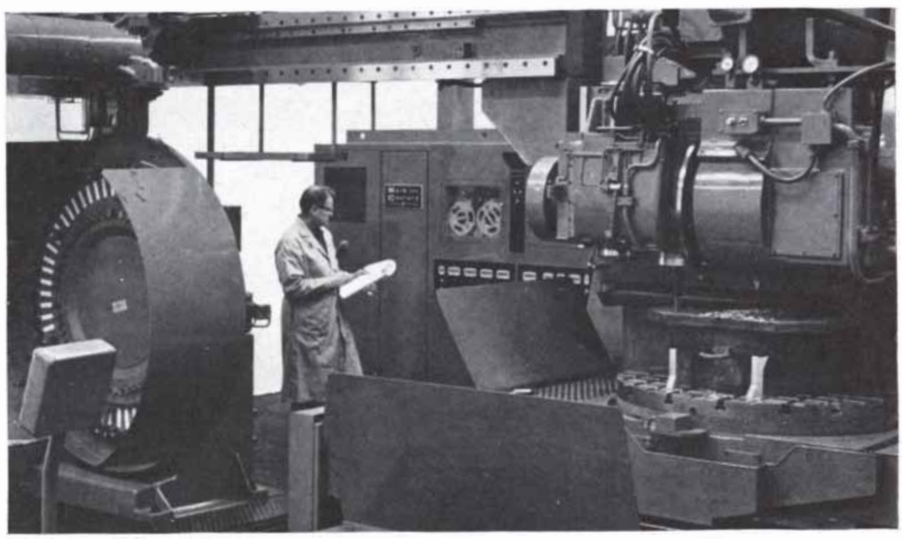


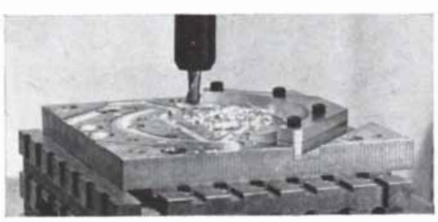


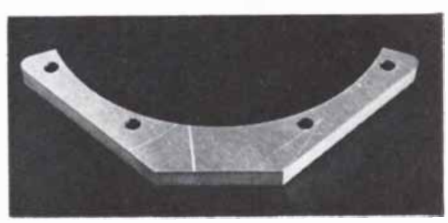
APT PART PROGRAM SYMBOLIC DATA

PART NO. PROGRAMMER DATE 8/17/66 PAGE OF JOB NO.

SYMBOL		INSTRUCTIONS	SEQ. NO.
PARTNO		RADIUS PLATE - AN APT PART PROGRAM	10
NOPOST			20
CLPRNT			30
OUTTOL	/	.0005	40
REFPT	=	PØINT / 0, 0, 1	50
HØLCRC	=	CIRCLE / CENTER, REFPT, RADIUS, 5.125	60
LINE 1	=	LINE / REFPT, ATANGL, 30	70
HØLE 1	=	PØINT / YSMALL, INTØF, LINE 1, HØLCRC	80
LINE 2	=	LINE / REFPT, ATANGL, 65	90
HØLE 2	=	PØINT / YSMALL, INTØF, LINE 2, HØLCRC	100
LINE 3	=	LINE / REFPT, ATANGL, -65	110
HØLE 3	=	PØINT / YSMALL, INTØF, LINE 3, HØLCRC	120
LINE 4	=	LINE / REFPT, ATANGL, -30	130
HØLE 4	=	PØINT / YSMALL, INTØF, LINE 4, HØLCRC	140
RADYUS	=	CIRCLE / CENTER, REFPT, RADIUS, 4.750	150
BASLIN	=	LINE / 0, -6.250, 10, -6.250	160







MACHINE TOOLS can be controlled by computers. At the IIT Research Institute the process begins with a conventional engineering drawing of a part to be machined, in this case a small "radius plate" (*top*). From the drawing the part programmer, writing in the APT (Automatic Programming for Tools) language, prepares a set of instructions that describe the part (*second from top*) and also the path to be followed by the tool. A computer calculates the detailed motions required to move the tool along that path, translating the programmer's word-symbols into numerical signals in the form of a punched tape. The tape controls the machine (*third from top*), in this case an "Omnimil" with 60 tools that are automatically interchangeable. A milling tool (*bottom left*) shapes the part (*bottom right*).

oriented" or "user-oriented" than the original languages; they are easy to learn because they resemble ordinary English and involve more or less conventional mathematical notation.

Another important development that makes the man-machine combination feasible is time-sharing [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128]. Computers can be operated economically only if they are kept constantly busy at productive work. A man working at a computer console cannot keep the machine busy, because the machine can receive a command, interpret and act on it and return a reply or a result in a few microseconds; then it must wait while the human operator digests the reply, thinks about it and decides on his next action. Enough people at individual consoles can provide the time-shared computer with a work load that will keep it gainfully employed.

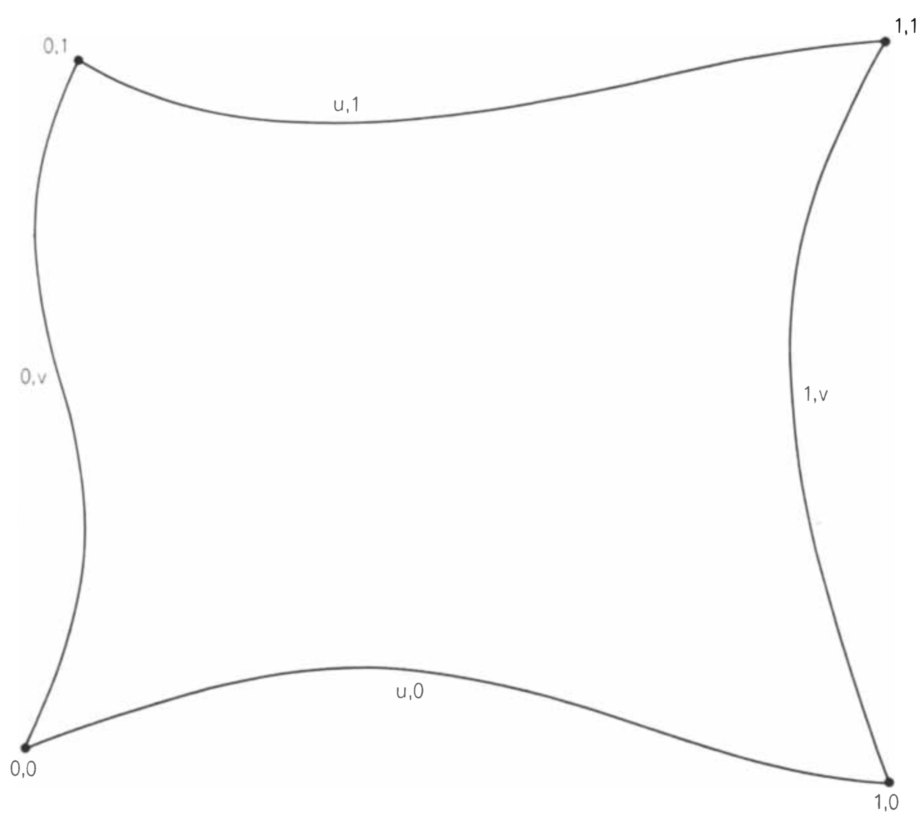
A third development is the display console, on which the computer can create symbols, graphs and drawings of objects and can maintain the display statically or cause it to move, simulating dynamic behavior. Together with input devices such as the "light pen," the display console becomes a window through which information can be transferred between the man and the machine.

The comfortable and congenial combination of man and machine made possible by these three developments has found some of its first applications in computer-aided design. By "design" I mean the creative engineering process, including the analytical techniques of testing, evaluation and decision-making and then the experimental verification and eventual realization of the result in tangible form. In science and engineering (and perhaps in art as well) the creative process is a process of experimentation with ideas. Concepts form, dissolve and reappear in different contexts; associations occur, are examined and tested for validity on a conscious but qualitative level, and are either accepted tentatively or rejected. Eventually, however, the concepts and conjectures must be put to the precise test of mathematical analysis. When these analytical procedures are established ones (as they are in such disciplines as stress analysis, fluid mechanics and electrical-network analysis), the work to be done is entirely mechanical. It can be formulated and set down in algorithms: rituals of procedure that can be described in minute detail and can be performed by a computer. Indeed, this part of the creative process *should* be done by the computer in order to leave man free to exercise his human powers and apply his human values.

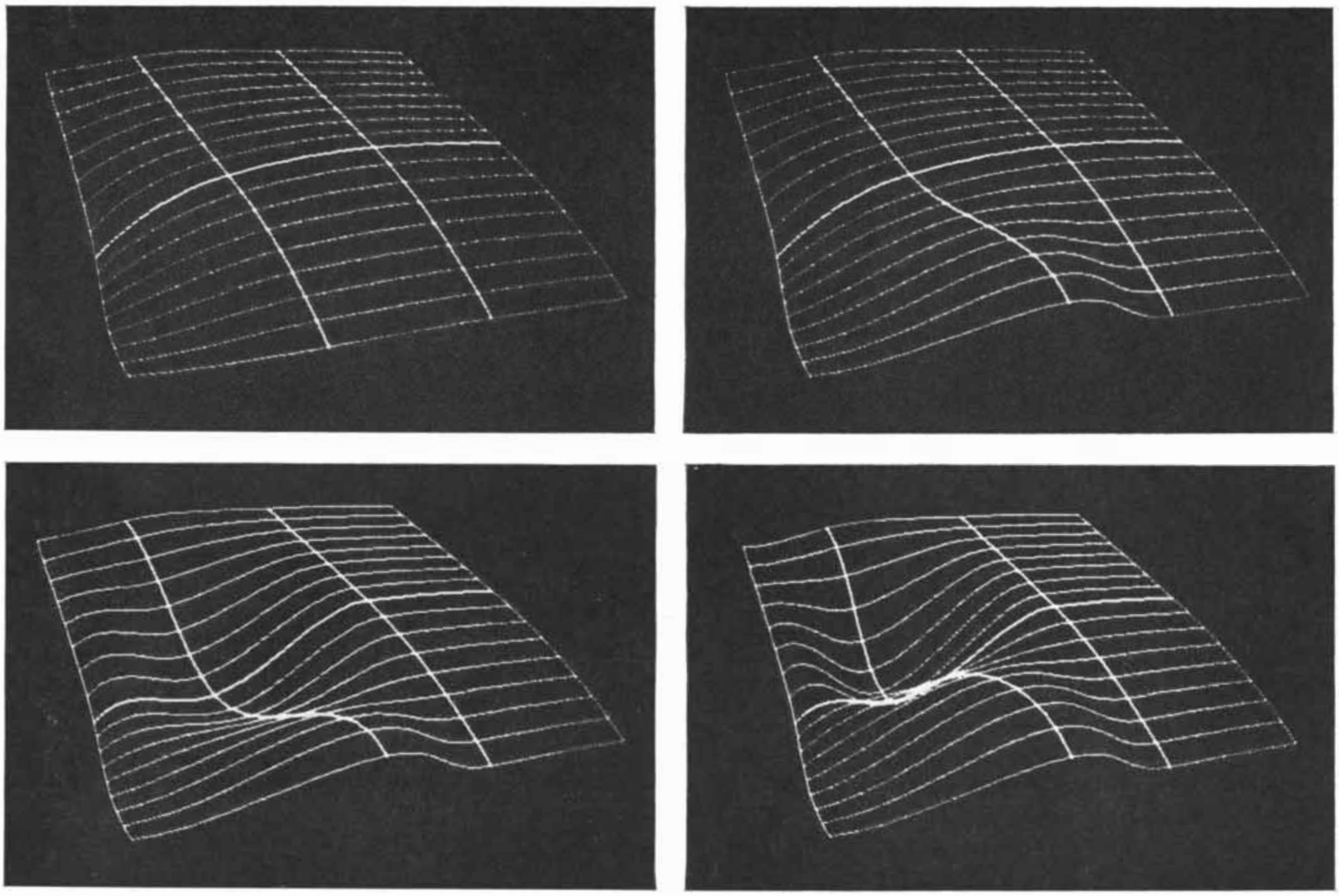
There is much talk of "automated design" nowadays, but usually automated design is only part of the design process, an optimization of a concept already qualitatively formed. There are, for example, computer programs that produce complete descriptions of electrical transformers, wiring diagrams or printed-circuit boards. There are programs that design bridges in the sense that they work out the stresses on each structural member and in effect write its specifications. Such programs are powerful new engineering tools, but they do not depend on an internal capability of creativity; the creativity has already been exercised in generating them.

I can best give some idea of the potentialities of computer-aided design by describing one of the tools that makes it possible. One of the early and epochal instances of man-machine symbiosis was the program called Sketchpad, which was completed late in 1962 by Ivan E. Sutherland of the Massachusetts Institute of Technology [see "Computer Inputs and Outputs," by Ivan E. Sutherland, page 86]. Sutherland used the TX-2 computer, an experimental machine that was built at the Lincoln Laboratory of M.I.T. with the idea of providing direct man-machine interaction at the console long before such a notion had much currency in computer technology and long before the notion of multiple users of a machine was much more than a dream.

When Sutherland began work on Sketchpad, the TX-2 had a cathode-ray-tube screen and a light pen as existing rudimentary pieces of equipment, but little had been done to exploit their possibilities. Sutherland set out to develop a system that would make possible direct conversation between man and machine in geometric, graphical terms. In the course of the development of Sketchpad he would invite people in to try out his system so that he could observe their reactions. On one occasion Claude E. Shannon, Sutherland's adviser on his doctoral thesis, wanted to perform a geometric construction. Rather than work out the construction on



COMPUTER-AIDED DESIGN of complex forms requires a method of describing surfaces mathematically. In the author's method free-form surfaces are built up from a number of surface "patches," each limited and defined by four boundary curves. Any point on the surface of a patch such as this one has three space coordinates, each a function of two independent variables, designated u and v, the values of which are allowed to range between 0 and 1.



MODIFICATION OF A SURFACE on the display scope of a computer is illustrated in these photographs from the Metal Stamping Division of the Ford Motor Company. The six-patch surface, representing half of a windshield, is shown at the upper left. The coordinates of a corner along one edge are raised (*top right*) and the coordinates of an interior corner are lowered (*bottom left*). Finally a tangent vector, which helps define one edge of a patch, is twisted. A requirement in manipulations of this kind is that the surface behave plastically rather than elastically: the change must be restricted to one site and continuity of slope must be maintained.

the console screen, Shannon automatically turned to paper and pencil to make a preliminary sketch. This came as a disappointment to Sutherland, who intended the system to be so congenial to the user that it would not intrude on his thought processes. He thereupon disassembled his program and rewrote it. It went through several such revisions, and it stands today as a classic of well-considered human engineering.

Learning to use Sketchpad is so easy that it can scarcely be thought of as learning; one simply begins and then becomes more skillful with experience. The program is remarkably versatile. Using Sketchpad, I was able one evening to set up and experiment with the following problems and constructions:

1. Evaluate a cubic polynomial equation. There is a simple geometric construction for polynomials of any degree and for real and complex values of the various terms. By manipulating the x variable with the light pen I could cause y to vanish, thus "solving" the cubic equation.

2. Construct a general conic section, or second-degree curve, using the basic principles of projective geometry.

3. Draw and set in simulated motion a "four-bar" mechanical linkage. Although such linkages are simple in outward form, their analysis is troublesome and is still the subject of investigation.

4. Draw a pin-jointed structure (such as a bridge), displace one of the joints (as if loading the structure) and observe the "relaxation" that is thereupon carried out by the computer to minimize the energy of the system, thereby simulating the actual deflection.

5. Plot the potential field typical of the flow of an ideal fluid within a region of specified shape.

Now, it is clear that these five problems are not much related to one another and that a conventional computer program written to deal with one of them would not be of the slightest use for any of the others. The computer did not contain a set of programs—one for each of the problems. Instead it had a flexible and quite general capability for performing a set of primitive geometric constructions and for applying a set of primitive geometric constraints. The computer played the role of an intelligent but innocent assistant, and together the machine and I set up and solved the problems. The time it took to do so was not more than 10 or 15 minutes in each case, so that something less than two hours was spent in not only achieving solutions but also experimenting with these solutions by changing the input variables. During this time the computer was mostly idle, waiting for me to decide what to do next. It probably spent not much more than five minutes in actual cooperative work.

This experiment in man-machine interaction is described not because the problems are significant or because the solutions were obtained efficiently. On the contrary, the computer was compelled to obtain solutions in an inefficient way compared with what might have happened if special conventional programs had been written for each problem. Five such special programs, however, could well have taken weeks to write and "debug."

Whereas Ivan Sutherland's Sketchpad

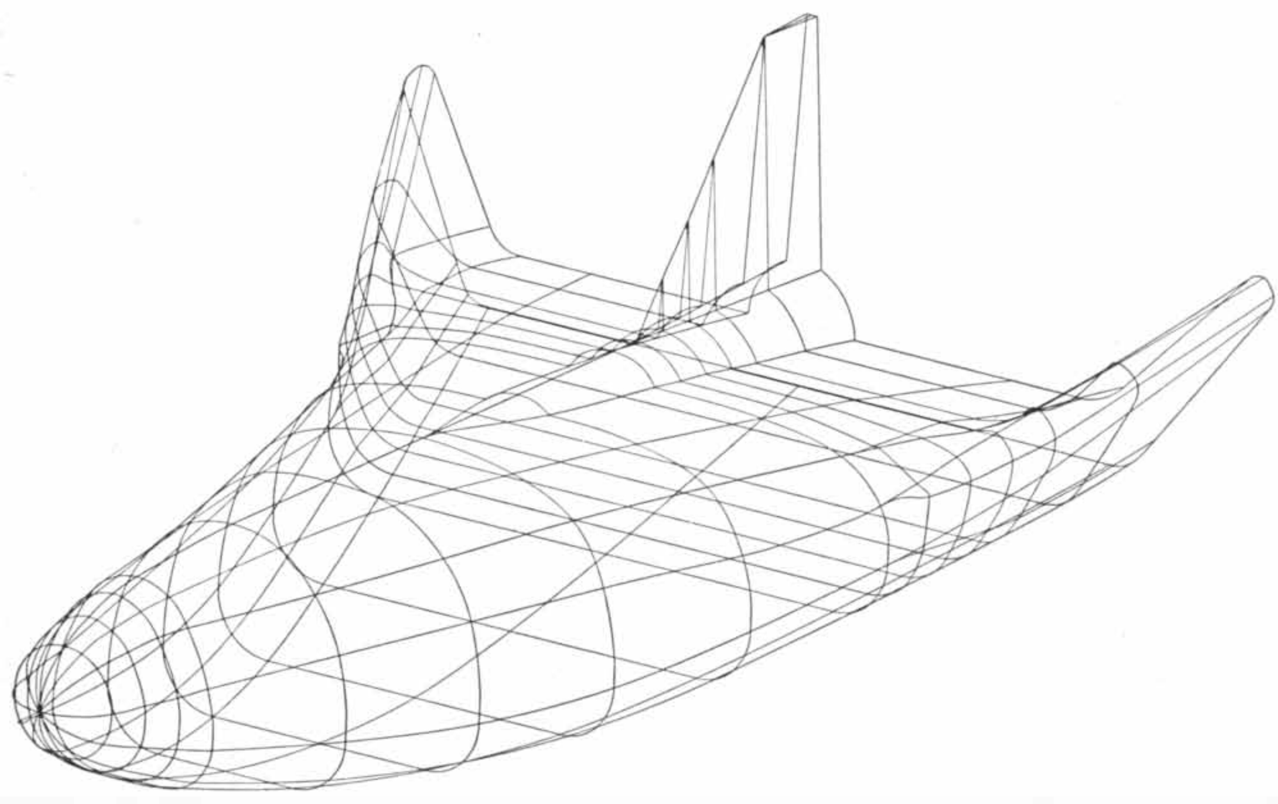
is purely geometric, William R. Sutherland, also of M.I.T., has extended his brother's work to include abstractions. With his program one can draw diagrams, attach meanings to them and then cause the computer to take appropriate action based on the diagrams and their associated meanings. One can draw a circuit diagram, for example, stipulate the characteristics and functional behavior of the elements of the diagram and then simulate the actual circuit performance. One can also draw a logical flow diagram of a computational procedure and then "activate" the diagram, so to speak, to obtain numerical results from numerical inputs to the procedural diagram.

The two Sutherlands' systems illustrate the striking possibilities of direct and natural communication with the machine. It is perhaps no mere coincidence that these highly congenial systems are graphical, and that the two-dimensional nature of their communicative form greatly enhances the ease of their use and the "transparency" of the interface they create between man and computer. The line of type from conventional typewriter keyboards has until recently been the only economically available means of "on line" communication with the computer. This one-dimensional string of symbols has had a somewhat stultifying influence on computer technology, partly because it bears little resemblance to standard and familiar mathematical notation and perhaps partly because its awkward syntactic constructions force some unnatural formulations in programming.

In many fields of engineering the geometric description of objects is a fundamentally important task. Airplane fuselages, ship hulls and automobile bodies are all complex free forms (as opposed to simpler specified forms such as spheres, cones, toruses or ellipsoids) and take many months to design and define by conventional methods. All kinds of smaller objects are also free forms: the hand set of a telephone, the bowl of a tobacco pipe, a differential housing of an automobile. In the design and ultimate detailed description of all such shapes the computer can make an extremely important contribution.

Objects are bounded by surfaces, and once the surfaces are designed and described we know a great deal about the object. The computer has made it possible, at least in principle, to perform all kinds of geometric operations on surfaces, provided that they can be described in mathematical terms. Unfortunately the traditional mathematical treatment of surfaces says a great deal about the analytical relations of surfaces that already exist and are expressible mathematically but very little about the problem of bringing them into existence. The emphasis has been on analysis, and until recently the study of the synthesis of surfaces has been neglected.

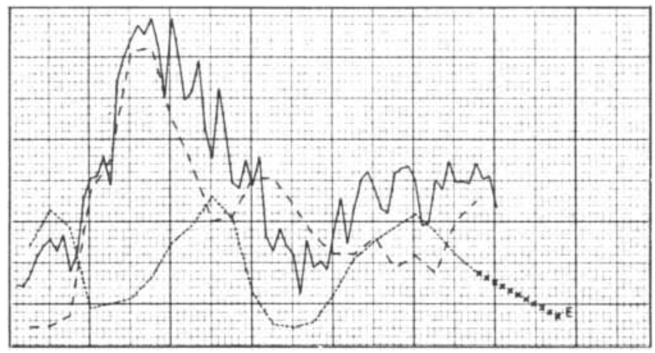
The design of a free-form shape begins with the design of a few salient outlines; once these important design curves are established, the complete and detailed description of the object's surface is to some extent a matter of mechanical extension of the implicit information. For example, an engineer can define a few contour curves for a casting. His drawing goes to a patternmaker in the shop, who creates a pattern in wood. The surface of the pattern is suggested by the design curves but is necessarily more completely specified; the patternmaker extends the original meager information by interpreting the intent of the designer. In the process he has done nothing inherently creative,



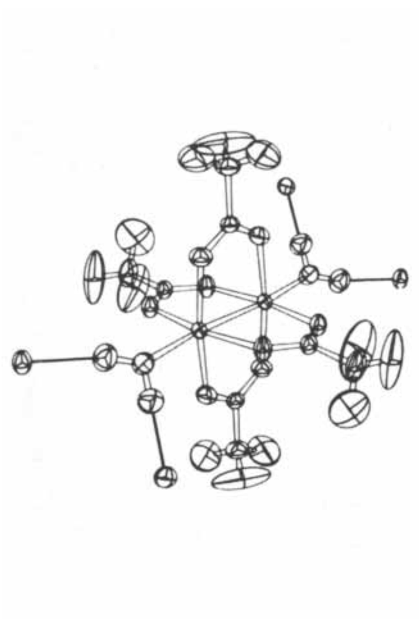
PERSPECTIVE DRAWING of a vehicle designed for reentry from space was produced by a computer-graphics program in the Aerospace Group of the Boeing Company. Orthogonal (head-on, top and side) views are prepared and points from these drawings are stored in the computer numerically. The computer projects the points and a tape from the computer drives a plotting machine.

Would you believe a CalComp plotter and any computer can draw pictures like these in seconds?

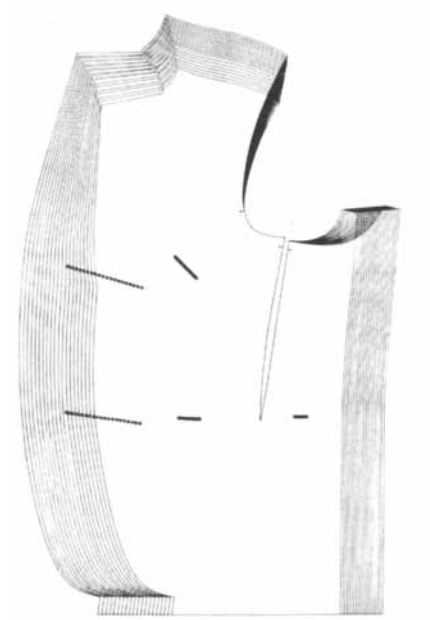
a perspective sketch of your new plant



statistical trend charts



molecular structure diagrams



apparel patterns, graded for sizes

and even the Mona Lisa

it can

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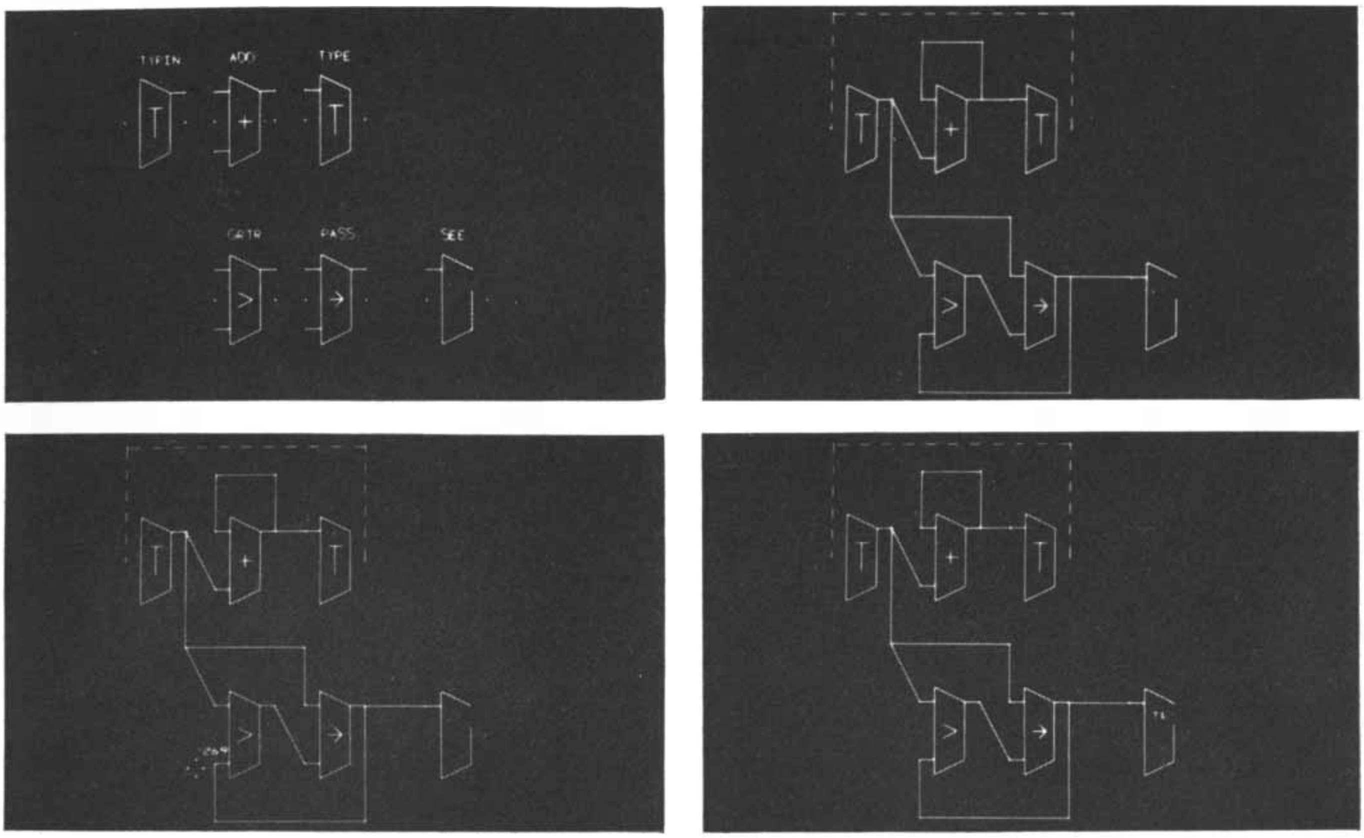

DIAGRAMS can be "activated" by a program devised by William R. Sutherland of M.I.T. Here a computer procedure is developed that will cause the computer to accept a series of numbers, print out the running sum and present in the last box of the display the largest of the input numbers. The individual symbols are displayed (*top left*) and are connected in a way that establishes the procedure (*top right*). One of the numbers to be added is introduced (*bottom left*) and finally the high number is displayed (*bottom right*).

but he has behaved like a benevolent, experienced and skillful machine.

Within the past few years a way has been found to make the computer play the part of the experienced patternmaker. The designer need only draw a few descriptive design curves; the computer immediately generates a surface that incorporates these curves, and the designer can either accept the surface or modify it by drawing additional curves. The surface so designed is contained in the computer in definite mathematical form and is constructed automatically in a fraction of a second. If the designer wishes, he can command the computer to operate a plotter and draw out a full-size contour map or other graphical representation of the object, or he can require that the computer control a multiaxis milling machine to carve out a model. If the designer sees in the drawing or model features that do not please him or do not satisfy the purpose of the shape, he can either make changes graphically with the light pen or indicate dimensional changes on the keyboard. The computer will immediately and obediently incorporate these modifications in its internal mathematical description of the surface of the object and will display the modified shape on the screen. The full-scale drawing can then be redrawn or the model recarved. When the shape is satisfactory, it can be machined from metal or any other desired material.

The saving in time and effort can be great. Five grossly modified versions of a ship hull were designed in the space of a few minutes on a Project MAC computer console at M.I.T.; each version was completely described by the computer in about a tenth of a second. A point anywhere on the hull could have been determined with a precision of one part in 10 million—certainly more than adequate precision for most engineering purposes. The mathematical algorithm that makes this possible is extremely simple in concept, and it is designed to be quick and easy for computer implementation. It is also quite general. It will accept virtually any kind of design curve: polynomials, transcendental functions and even freehand sketched curves possessing no descriptive mathematical formula whatever.

Given this power to do what might be called mathematical sculpture, the engineer can use the computer representation of an object as the base for a variety of analytical treatments. He can perform stress analyses, predict pressures and other fluid forces on airplane and ship shapes, simulate dynamic effects such as vibration, study heat flow or do any of a number of calculations that depend partly on precise knowledge of the shape in question. The surface algorithm is easily extended to hypersurfaces of any dimensionality, making possible the graphical presentation of multidimensional functions. It has been learned that such surfaces, even though they do not exist in our three-dimensional universe, can be exhibited on a cathode-ray-display tube and, when they are observed in dynamic motion, can convey meaning and elicit understanding.

In the near future—perhaps within five and surely within 10 years—a handful of engineer-designers will be able to sit at individual consoles connected to a large computer complex. They will have the full power of the computer at their fingertips and will be able to perform with ease the innovative functions of design and the mathematical processes of analysis, and they will even be able to effect through the computer the manufacture of the product of their efforts. Through their consoles they will

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Measurements of the Micropulsations of the Earth's Magnetic Field

Micropulsations are now being measured on a long term continuous basis in a previously unmonitored section of the Midwestern United States, hopefully leading to further correlations between these magnetic variations and geophysical disturbances.

For a long time scientists have known that solar activity has repercussions within the magnetosphere of the earth. The plasma clouds from the sun generate magneto-hydrodynamic waves which are observed on the earth as micropulsations of the earth's magnetic field. Since about 1936 scientists have been measuring these micropulsations at various locations on the earth's surface and have attempted to correlate them with observed geophysical phenomena. By so doing they have determined the origins of some disturbances but the causes of many others remain unknown.

The micropulsations normally being measured are in the extremely low frequencies under 5 cycles per second and have amplitudes ranging from several 10's of gammas to milligammas. The shape, amplitude, frequency and nature (whether impulsive or continuous) of the micropulsations imply different causes. Correlation is attempted with observed data on physical occurrences obtained in many ways including information from instrumented balloons, rockets and satellites.

A problem in correlating data is that although many measuring stations exist, vast areas of the earth are not adequately covered as yet. The Midwest region of the United States from the Great Lakes to Colorado has been such an area. The Honeywell Research Center is now establishing a station in this region.

All such stations must be located in an area of unusually low electrical noise and also must be near a research base for equipment maintenance and data gathering. Fortunately the University of Minnesota has maintained a virgin forest about 35 miles north of Minneapolis for natural history research. The University has now permitted Honeywell to locate its station in the center of this unique forest.

Housed in a trailer furnished by the U. S. Bureau of Standards, the present Honeywell facility consists of signal conditioning equipment, a low noise amplifier, a magnetic recorder and a multi-channel strip chart recorder. Current work is directed toward the establishment of a 3-axis system.

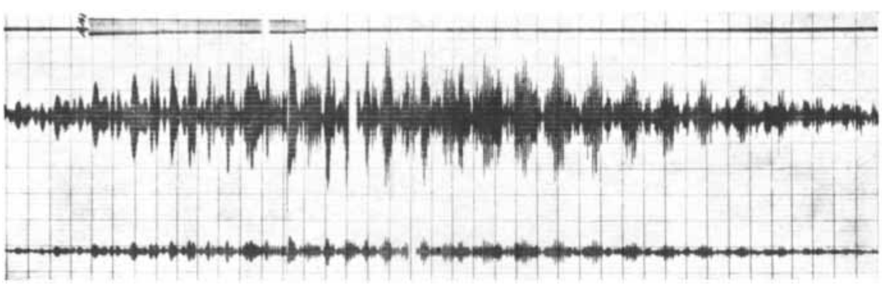

FIG. 1. Segment of micropulsation record showing high- and low-sensitivity traces. Recorded at 25 inches per hour at Honeywell's Cedar Creek Station.

Of particular interest to Honeywell scientists is the micropulsation known as a "pearl", so called because its signal, when charted, resembles a pearl necklace. (See Fig. 1.) Less is known about the "pearl" than other low-frequency signals and although many hypotheses have been set forth regarding its origin and nature, none have been proven.

Honeywell scientists are using a standard speed-up technique to study the "pearls". The taped low-frequency signals are played back at higher speeds, enabling the scientist to hear when a disturbance occurs. A 30-minute "pearl" pulsation is then condensed into short blips. Interesting portions of the tape identified by the blip are fed into a sonograph which displays the signal's frequency, time and intensity. The scientist using an XY plotter will play different channels simultaneously to determine the polarization and temporal variation of the field.

The visual trace (Fig. 1) helps to determine the interesting portions in order to concentrate the analysis. It also provides a visual record which can be published for correlation with other stations.

Many "pearls" have now been recorded at the Honeywell station. It is hoped that some new understanding of the causes of phenomena in the earth's upper atmosphere will result.

If you are engaged in research on micropulsations and wish further information concerning Honeywell's plans for work in this area, you are invited to correspond with Mr. Van Kardashian, Honeywell Research Center, Hopkins, Minnesota. If you are interested in a career at Honeywell's Research Center and hold an advanced degree, write to Dr. John Dempsey, Vice President of Research at this same address. Several important new staff positions are unfilled at the present time.

Honeywell

be in communication with one another to ensure that the separate elements of the design are compatible. Engineering standards, parts catalogues and other data will be accessible through the display screens of their consoles. Some mechanical parts will be produced directly from the design information generated within the computer, without the necessity of drawings. (When drawings are required to provide information for final assembly or for maintenance manuals, these drawings will be prepared by the computer from the primary design information, and the drawings will even be tailored to match the use. For example, electrical wiring drawings will subordinate actual structure, showing only enough to clarify the task of the electrician.)

It would be difficult to compile even a representative list of the agencies and individuals who are making contributions toward the realization of this new age of the computer. At M.I.T., Douglas Ross and I have been directing efforts toward this goal under Air Force sponsorship for about seven years. In the Electronic Systems Laboratory, Ross is engaged in a formidable effort in the areas of data structures, computer languages and general compilers for engineering design. My group in the department of mechanical engineering has been working on graphical displays and on design tasks such as three-dimensional stress analysis, the solution of equilibrium field problems, kinematics and data storage and retrieval. Almost all universities with computer facilities are engaged in some phase of the problem. Work closely parallel to the work at M.I.T. is being done by Bertram Herzog and his colleagues at the University of Michigan. In industry the Lockheed Aircraft Corporation, the General Motors Corporation and the Ford Motor Company have experimental computer-aided design systems in operation, and these systems are beginning to be used to a limited extent in production engineering. The Boeing Company and the Douglas Aircraft Company are involved in similar activities.

Much energy and talent is being devoted to making computer-aided design and man-machine interaction a convenient everyday reality, and as time goes on more fresh effort is being channeled into this exciting enterprise. One may hope that engineers, economists, psychologists, sociologists and other men can help to provide the appropriate human adjustments to it.

Moving air is easy . . . controlling it takes an expert

When Aristophanes wrote his comedy in 405 B.C., he described the call of The Frogs as brekekekex, ko-ax, ko-ax. Little did he think that man one day would use a sound spectrogram to catch the call of a tree toad at a dominant frequency of 1,200 cycles per second. We know now that toads and frogs bark, boom, bray, chirp, peep, trill and just go "jug-o-rum." When Mr. Frog goes acourtin' and winds up the old throat sac, Mrs. Frog gets the message. Knowing how to move air and control it is our business, too. You'll give a long locomotive after talking to our Application Engineers. They're ready, anytime.
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navigate

Saturn's lunar mission is uniquely complex—that's why its guidance, navigation, and control systems are on-board.

□ On its launch pad Saturn V and its Apollo spacecraft will stand 36 stories high. It will weigh more than 3,000 tons. And all the energy it

guide

uses to send men to the moon will be controlled from a 3-foot stage of Saturn called the Instrument Unit.

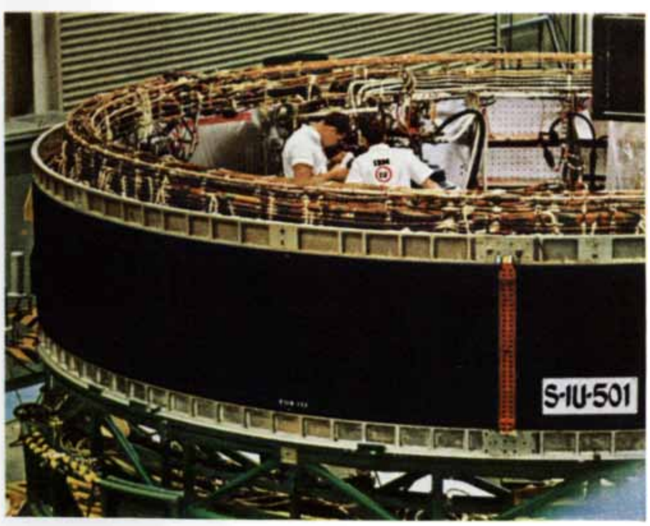
□ Designed at NASA's Marshall Space Flight Center and assembled by IBM Federal Systems Division, the Instrument Unit is the nerve center of the mighty Saturn launch vehicle. Within this aluminum ring, 21.7 feet in diameter, are more than 60 electrical and electronic units, integrated to provide the vehicle with guidance, navigation, control and data handling systems.

□ The IU's sensitive instruments process millions of bits of data every few minutes. During 10 minutes of powered flight, its guidance system measures acceleration and vehicle attitude 25 times a second. It determines velocity and position every second, and calculates and issues steering commands to keep Saturn on course.

□ At the same time, the Instrument Unit samples 200 sensors that measure environment and systems performance. The IU tests sound levels, temperatures, pressures and vibration levels more than 7,000 times a minute. It precisely commands engine cut-off and initiates stage separation and engine ignition in the next stage.

□ Acting as a powerful information handling system the Instrument Unit records and relays flight information to ground stations.

□ Before launch, the Instrument Unit aids in countdown checkout. Under blockhouse control, the on-board IBM computer checks itself and the Saturn vehicle. It tests switch selectors in each stage, orders first-stage engines to gimbal for visual



Instrument Unit 501 in final assembly at IBM Huntsville.

Full-size Saturn V/Apollo model is rolled out of NASA's Vertical Assembly Building.

control

observation, and conducts similar readiness tests. After liftoff, the Instrument Unit helps ground controllers track Saturn's flight for range safety and for updating on-board systems with new guidance data.

□ In earth orbit the Instrument Unit commands engine ignition to put Apollo on trajectory to the moon. Once on course, it stabilizes the stage as the Apollo command and service module separates and docks with the lunar module.

□ IBM's systems management responsibility for the IU is focused in Huntsville, Ala., at a new 1,800-man facility. Here, IBM assembles and tests Instrument Units for the current series of Uprated Saturn I's and Saturn V moon rockets.

□ Before each IU is approved for flight, it gets a rigorous 8-week automatic systems checkout, including simulated launch and flight.

□ IBM is designing IU configurations for future Saturn flights and is providing programs for the on-board computer and mission support.

□ Instrument Units are shipped to NASA's Kennedy Space Center. Here 700 IBM technicians support launches of Titan, Gemini and Saturn. In Owego, N.Y., where Saturn's computers are made, and Houston, Texas, where IBM people perform critical jobs in NASA's mission control facility, and at NASA tracking stations around the world—IBM helps carry out the lunar program.

□ Since the early days of Vanguard and Mercury, IBM people have played significant roles in this country's major space programs. And IBM computers, including the newest – System/360 – have kept pace with the constantly mushrooming information processing needs of advanced space programs.

□ Like flights to the moon.

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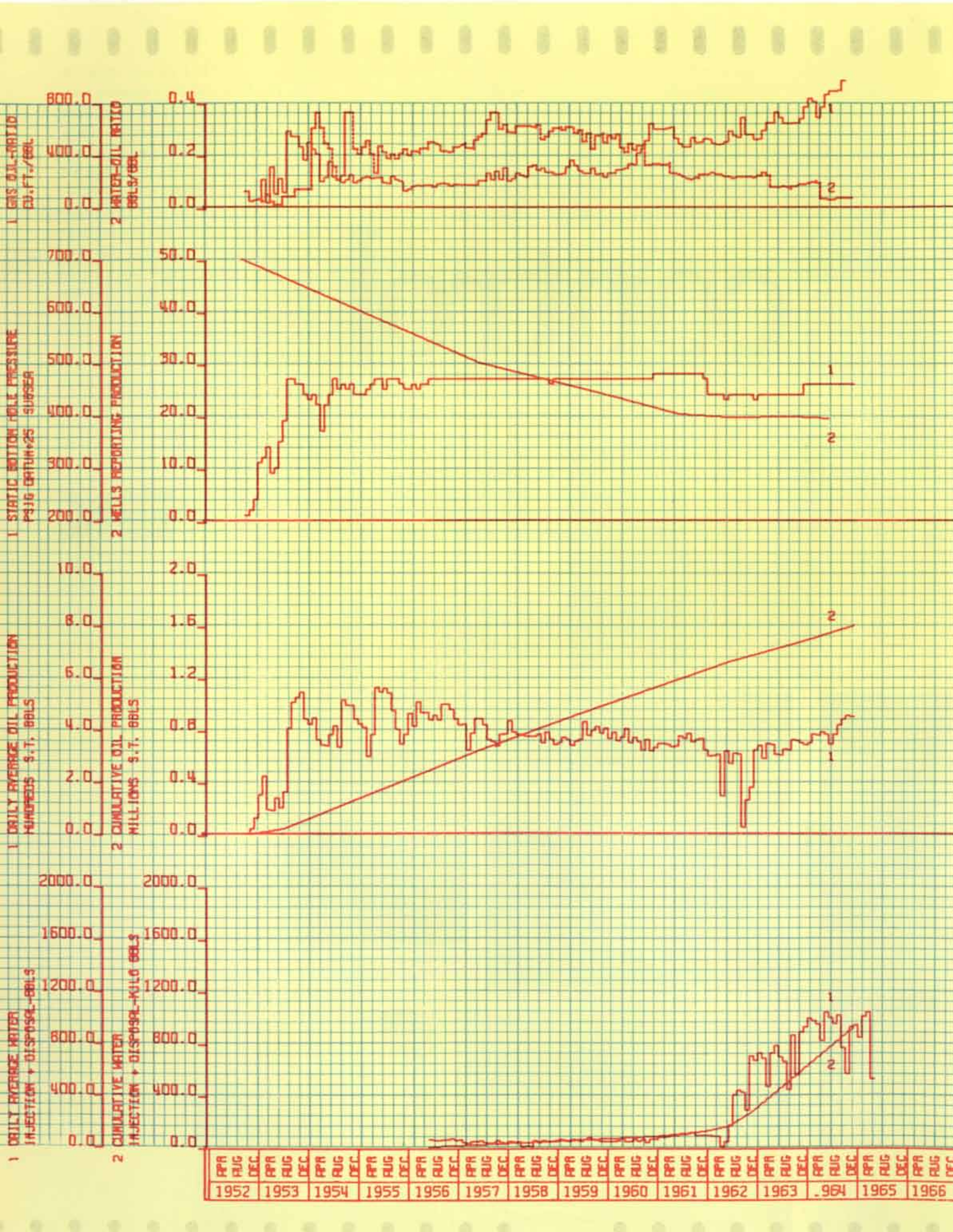
Technicians precisely assemble components of the Saturn computer.

IBM computer and data adapter installed in the Instrument Unit.

Saturn computer in IBM's simulation laboratory.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The Uses of Computers in Organizations

As computer systems take up more tasks in human organizations they come to resemble the organizations themselves. Ultimately they will serve the organization's key functions of communication and control

by Martin Greenberger

The computer systems under development today are beginning to mirror man and his industrial society, both in structure and in the pattern of their evolution. Our industrial civilization is characterized by the division of labor, the specialization and routinization of functions, mechanization, stratification of control and a hierarchical form of organization that integrates the activities of planning, management and operations. Coordination is accomplished by an elaborate system of information-handling and communication. The computer is being brought into the organization primarily to help with information-handling, but in the process it is incorporating in its programs almost all the characteristics of the organization as a whole.

This may come as no surprise, since computer systems and programs are designed by human beings and might therefore be expected to assume aspects of man and his organizations. Indeed, all the machines man has devised possess the characteristics of organizations to some extent. But the computer is not just another machine. It has a versatility, a logical flexibility and an open-endedness—an ability to grow—that is not matched by anything short of the living organism. The computer, a comparatively recent addition to the organization, has within it the potential for completely remolding the organization. Accordingly it has new and important implications for the future of human society. In this article we shall first consider the past and present uses of the computer in the organizational setting and then explore the computer's possible future in that setting.

The use of the digital computer as a generally available (that is, commercially produced) tool is only 15 years old. Its first applications were in science and engineering. Its early users took a rather restricted view of its capabilities. It was put to work composing lengthy numerical tables and performing other prosaic calculations. Soon, however, its wider potentialities gained the interest of the military authorities, among others, and substantial amounts of money were made available to promote its evolution. The digital computer became a yeast in research and development. Without the computer there might be no nuclear power plants today, no communication satellites, no space program, perhaps no commercial fleets of jet airplanes. In the laboratories of science the computer likewise grew rapidly in power, versatility and esteem [see "The Uses of Computers in Science," by Anthony G. Oettinger, page 160]. By expanding the ability to deal with complex problems, the computer has stepped up the rate of scientific and technological advance.

The story is much the same for the use of the computer in business and government. Its first employment outside the fields of science and engineering was by the Bureau of the Census in 1951. There and in the business firms that began to use the machine it was assigned exclusively to standard clerical and statistical tasks. Most engineers and business executives foresaw little use for the computer in business except for record-keeping and other mechanical operations. The General Electric appliance division installed a UNIVAC I in 1954 and gave it the job of preparing the payroll, which was successfully achieved only after a certain amount of agony and mishap. A few banks, insurance companies, mass-circulation magazines and public utilities arranged to use digital computers for customer accounting and billing; some manufacturers and distributors applied the computer to inventory control.

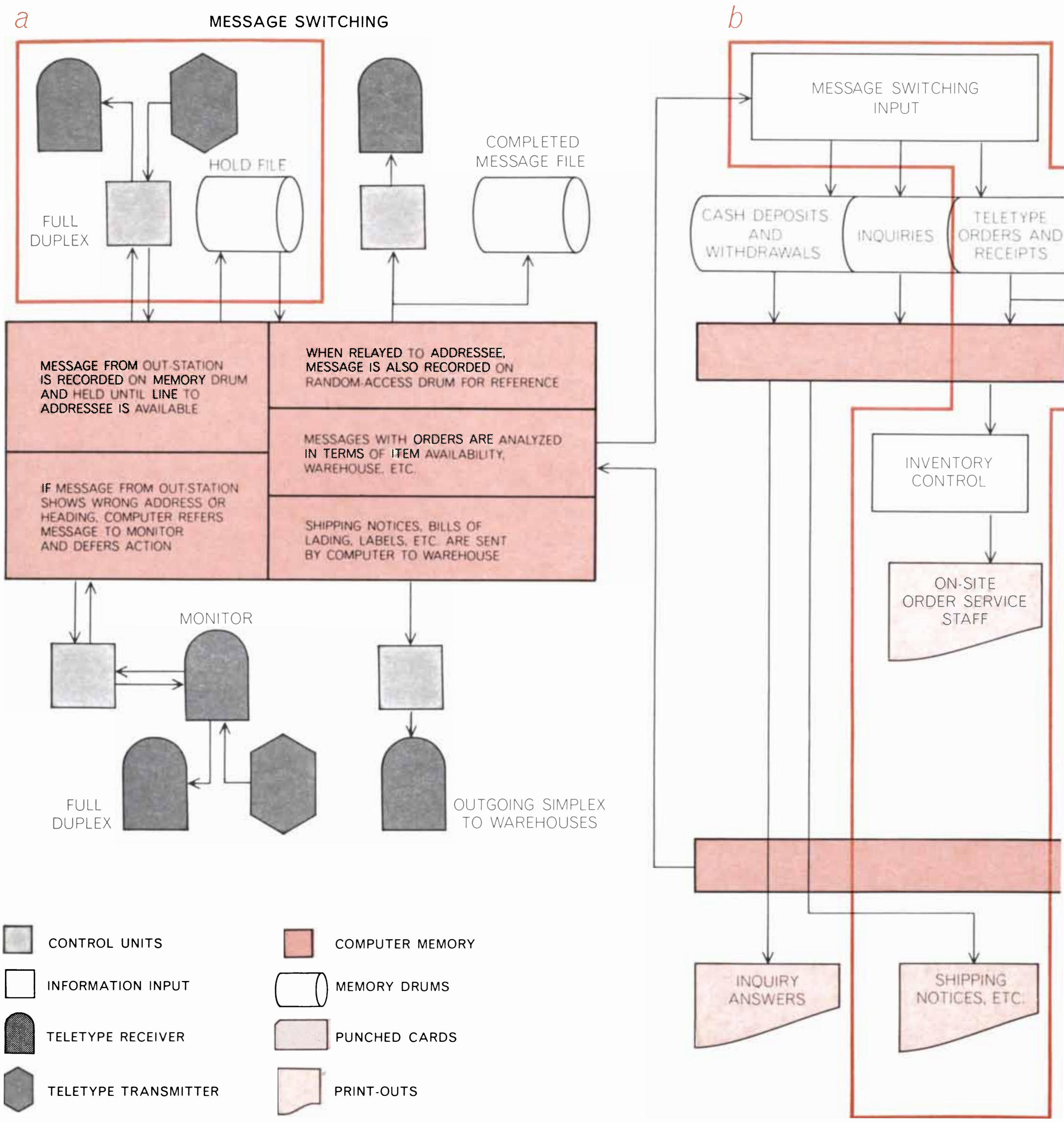
It is startling to recall that this was the situation barely a decade ago. Today tens of thousands of digital computers are employed in business and government in the U.S. By virtue of their flexibility and great improvements in their speed, capacity and reliability, they have been able to take on a wide variety of new jobs. The computer has been graduated from a specialist in drudgery to an information processor adept in a broad range of functions. Interestingly enough, this broadening of the computer's capability has been achieved in part by creating a high degree of specialization within the machine. As the art of programming advances, the devices used for the organization of computer programs are coming to resemble those that have proved

PERFORMANCE CURVES, automatically plotted from data stored in a computer's memory, present eight key aspects of operations at an oil field in the Canadian province of Alberta. The two lower pairs of curves on the opposite page plot the daily averages of oil production and water injection against the field's cumulative totals in these categories. These and the production data shown in the two upper pairs of curves provide a continuous performance record of the kind that many industries produce today from computer-stored information as a basis for decision-making. This display was generated in less than four minutes from production records kept by the Triad Oil Company by means of a computer-linked plotting device that is manufactured by California Computer Products, Incorporated.

useful in the organization of human society. The large programs today contain a considerable array of differentiated services and multiple levels of control.

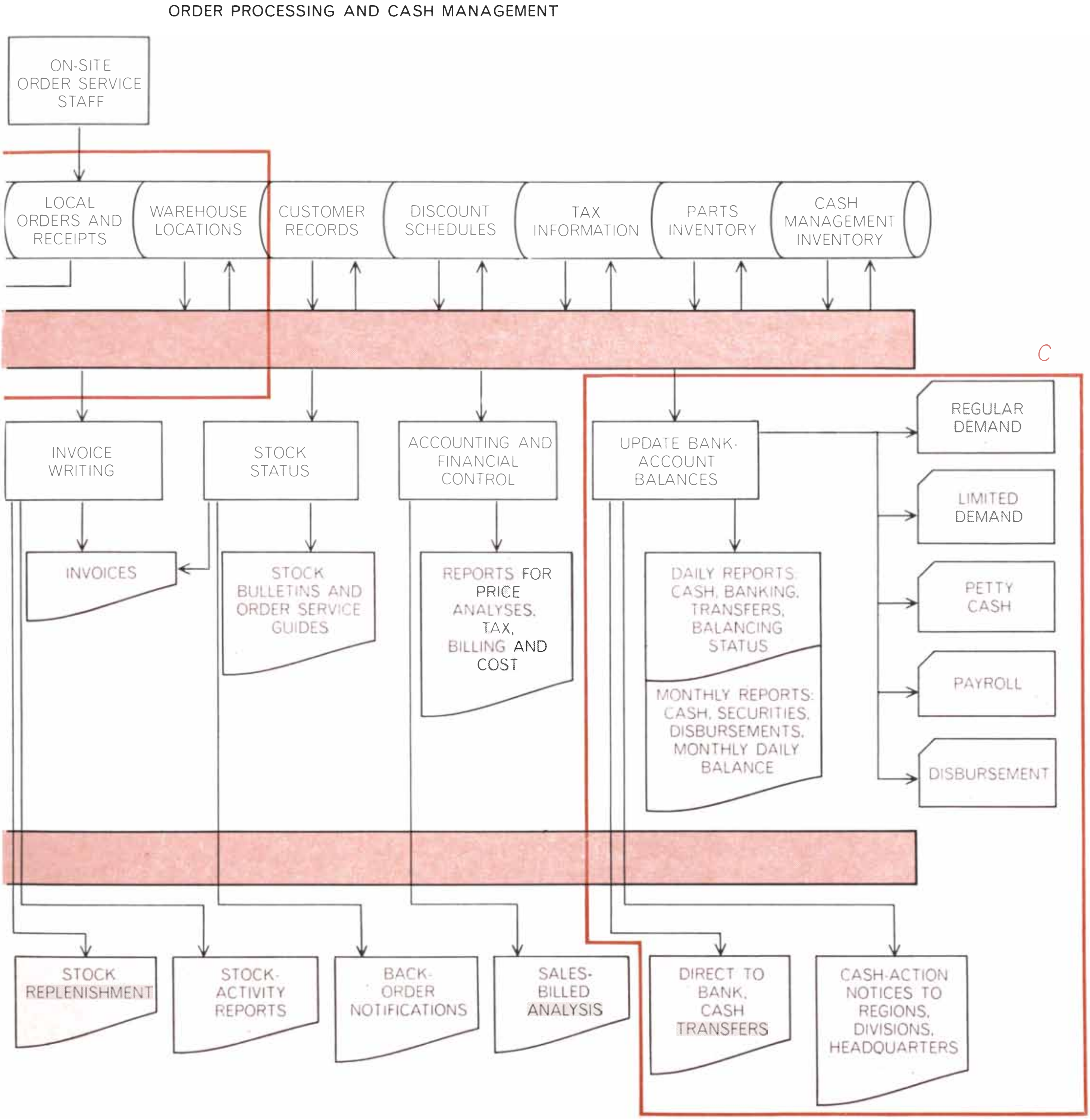
The programmed unit of specialization in a computer system is called a routine. It is a set of instructions for performing a distinguishable task; it can be likened to a human worker doing a specific job or using a particular skill. There are routines that exercise control (managers) and others that execute operations (workers). Subserving the specialized operations are standardized routines, called subroutines, that perform functions of general utility.

Computer routines are the programmer's device for coping with complexity. They not only enable him to break down a complex program into manage-

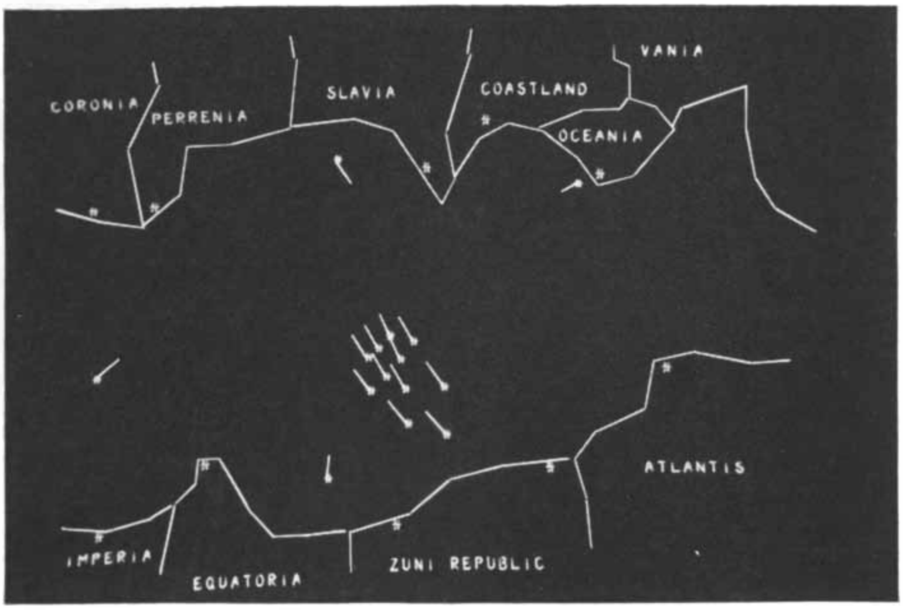


CORPORATION NERVE CENTER has evolved from a computer-assisted message-relay system developed by the Westinghouse Electric Corporation in the early 1960's. The diagram shows the scope of the system's activities in simplified form; some examples of its many functions are outlined in color. The center, located in Pittsburgh, was planned as a control point for teletype communications between Westinghouse's more than 300 sales offices, distributors, warehouses, factories and repair centers throughout the U.S. At first the center's computers served such simple purposes as overnight memory storage of a West Coast message to an East Coast able parts but also confer other important advantages. A program can be organized in modules, or building blocks, consisting of self-contained routines, and this makes it easy to reach in and replace a defective module or to add a new one. Most large computer systems have been built by the modular approach. Those that have not have demonstrated how important it is to allow for change and growth. Modularity facilitates growth. Just as new workers, skills, machines and instruments can be added to an industrial or research establishment to enlarge its scope of operations or deepen its capabilities, so in a modular computer system new routines can be added to improve its operation.

The modular structure is also a great convenience when a team of program-



addressee received after close of business and automatic forwarding of the message the following day (*a*). The computers were also programmed to analyze incoming orders and to check them automatically against continuously revised inventory compilations. This program directed the computers to forward orders selectively to the stocked warehouses closest to the originators of the orders (*b*). Computer analysis of sales and purchases soon produced an additional bonus (*c*). A running record of nationwide cash receipts and disbursements has permitted banking practices that substantially reduce cash surpluses and allow investment of these once idle funds.



COMMAND PROBLEM appears in a cathode-ray-tube display that combines computer-generated data with a projected background. The 11 comet-like dashes (*center*) represent a navy convoy crossing a sea bordered by a number of imaginary nations. One convoy vessel signals distress; the command problem is to avoid additional disruption of the convoy by requesting help from the nearest friendly port or from independent fleet units. The computer can draw from memory and display such facts as the treaty status and repair facilities of the nearest ports and mission priorities of fleet units in range of the vessel. The display console, designed as a visual aid to command, is produced by the Bunker-Ramo Corporation.

mers undertakes to collaborate on a large project, as a group of us at Harvard University did in 1957 in the course of building a demographic model of the U.S. economy. Each member was assigned to an independent section. We were able to work in relative isolation; responsibilities were clearly established; program checking was simplified, and the project proceeded along several lines simultaneously.

A good illustration of modular design is our system called OPS (for "On-Line Process Synthesis") at the Massachusetts Institute of Technology. It was developed within the time-sharing system of Project MAC, which is itself constructed on the modular plan [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128]. OPS is one of numerous user programs filed in the memory of the time-sharing system. This particular program, however, like a division of a large corporation, is a complete operating system in its own right. It has its own retinue of control routines and a wide assortment of subroutines and operational programs known as "operators." There is an operator corresponding to each of the customary statements in an algebraic programming language, such as FORTRAN or ALGOL, and there are also operators for individually tailored and complex compounds of these statements. One operator solves general linear programming problems. Another does a multiple regression analysis. A third locates the critical path in a network. A fourth performs a general computation involving vectors and matrices. A fifth smooths a time series, providing an economic forecast. A sixth schedules an event during a simulation run. A seventh presents information in tabular format. And so on. The user can add operators that are particularly relevant to his own interests. By its modular structure the OPS system makes room within the physical limitations of the machine for a high degree of growth and variety.

A user of the OPS system addresses each operator by its name, which may be an English word such as SET, PRINT or READ. He can combine operators into a compound operator and give it a name of its own. Since the OPS system runs in a time-sharing environment, the user can program himself into the computer operation and from his on-line terminal perform those aspects of the operation that call for human judgment or are amorphous and undefined. In the same way he can control the operation of the program externally.

Thus time-sharing makes possible the flexible inclusion of people in a computer operation. The potential for human participation is particularly significant in operations conducted in "real time." This term simply means that the computer interacts with the external environment and carries out appropriate operations as the situation develops. In other words, the computer is linked directly to the work to be done in the real world. A straightforward example is the guidance of a missile or space vehicle to its destination by continual computer adjustments to the changing conditions en route. A more elaborate example is the SAGE computer, which receives information on possible enemy activity from radar stations, aircraft and picket ships spread over a vast area. The computer must rapidly summarize on display screens the information coming in from all these sources, and it must act as adviser and controller for any defensive action that is indicated.

It is with the advent of real-time systems that the organization of programming has begun to resemble human organizations most closely. A real-time system requires considerably more complicated programming than the more conventional batch-processing operation does. Whereas in batch processing jobs typically are fed to the computer continuously and serially from a single tape on which they have previously been accumulated, in a real-time operation they can enter instantly, sporadically and simultaneously from any of many remote terminals connected to the computer. Jobs are processed transaction by transaction rather than batch by batch. Since the execution of the program is interrupted whenever external conditions dictate, a variety of special routines must be provided to handle each of the contingencies. To make the system workable, information within the computer must be arranged in randomly accessible form, and programs are needed to make storage and retrieval of this information convenient. The result may be a complex organization of specialized routines whose coordination and control are a central function of the real-time operation.

The technology for real-time systems is already fairly well advanced, thanks largely to military developments such as SAGE. The available terminal equipment, however, particularly that providing for the input and output of information in graphical form, is still too expensive. Moreover, such "conversational" teleprocessing is costly, because present communication systems are designed for voice signals and continuous transmission of data, not for scattered bursts of data. Nevertheless, in spite of the temporary obstacles of high cost and

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the relative difficulty of real-time programming, real-time systems are already entrenched in the military sphere and have been making decided progress in business and industry.

The first commercial application of a real-time system on a large scale was the SABRE reservation system of American Airlines. Its computer center is in Briarcliff Manor, N.Y. To this center more than 1,000 reservation clerks at airports and offices throughout the U.S. address their queries and instructions. The clerks type their messages into the computer from their typewriter terminals, using a code SABRE can comprehend. The transactions occur at unpredictable times, placing an uneven load and a wide variety of demands on the system. Yet SABRE is tuned to respond to a request within three seconds.

Several airlines and railroads have followed this lead and installed reservation systems of the same type. Real-time computers soon will also be landing airliners in fog and scheduling railroad freight-yard activities and the movement of boxcars. A computer will control the running and spacing of the high-speed passenger trains of the new rapid-transit line in the San Francisco-Oakland bay area. Real-time systems are being set up to control automobile traffic in large cities, including New York. It is not farfetched to anticipate that someday an integrated information-and-control system will link together not only transportation facilities but also hotels, motels, car rentals and all other agencies of travel.

In the field of finance real-time systems are being put to work by banks, insurance companies and stock markets. Many savings banks have installed on-line systems in which deposits and withdrawals are recorded directly in a computer. Commercial banks are beginning to use random-access computers for handling demand-deposit accounting and recording stock transfers. Insurance companies are planning to make the files of their policyholders available to their agents in field offices through on-line queries to the central office. Several stock-quotation services enable brokers and their clients to obtain the price of a security simply by dialing the computer. The New York and American stock exchanges are embarked on programs that will facilitate the eventual automation of all their floor activities, with the possible exception of the setting of prices. It is perhaps not overly fanciful to foresee a day when most trading and financial transactions will be carried out not on the floors of exchanges and in the conference rooms of banks but over computer communication networks linking together widely separated offices of the transactors. Such a development might have important implications for the future of our cities, one of whose chief functions at present is to serve as financial centers.

Real-time computers have also entered the fields of retail and wholesale commerce. There are now service companies that make real-time computation available in the manner of public utilities to enterprises of modest size. One such company is the Keydata Corporation in Cambridge, Mass. Some of its subscribers are wholesale distributors. When a sale is made, a clerk types an invoice for the customer on a teletypewriter that is connected to the Keydata computer by a leased telephone line. The clerk identifies the customer simply by a number; the items he has bought are also identified by number, and the only other information supplied is the amount of each item bought. The computer fills in, from information stored in its files, all the rest of the necessary data for the invoice: the date, the invoice number, the name and address of the customer, descriptions of the items sold and their prices. It calculates and prints the total amount of the sale and checks for clerical errors. All in all it types about 80 percent of the information on a typical invoice. The computer retains information concerning the transaction and therefore is equipped to provide the services of inventory control and sales analysis.

In industry one of the pioneers in the development of real-time systems has been the Lockheed Missiles and Space Company. Its computer center at Sunnyvale, Calif., operates an "automatic data-acquisition system" that collects information on work flow from more than 200 factory stations spread over a 300-mile radius from the center. The system records and controls the movement of more than 200,000 separate items manufactured or stored at these locations. Also connected to the computer are 25 stations from which, on inquiry, prompt information can be obtained about the location of shop and purchase orders, inventory levels and labor charges. The system, which has been operating since 1962, has saved the company millions of dollars in its Polaris and Agena programs. It has relieved supervisory personnel of much pressure and confusion and has freed them to devote more time to planning. It has also eliminated hundreds of jobs in the areas of purchasing, expediting and production scheduling.

The reduction of jobs by the computer and its acquisition of detailed data about the activities of workers produced an eruption of resentment among the workers. This subsided after Lockheed put restrictions on the use of the data by management, instituted training programs and assigned to other jobs employees who had been displaced by the machine.

Probably the most extensive and advanced use of a real-time system in industry today is that at the Westinghouse Electric Corporation. Its telecomputer center in Pittsburgh is becoming the nerve center of the corporation. The center started operating in 1962 as an automatic switchboard for messages in the teletype network that serves all the Westinghouse divisions. Today this system, in continual communication with about 300 plants, field offices, warehouses, distributors and appliance-repair centers, is taking over the functions of inventory control and order processing on a vast scale. It has also begun to take a hand in production control and is steadily moving into new fields.

The improvements in the company's operations have been dramatic. By directing shipments to customers from the nearest warehouse that has the ordered item in stock the system has speeded up deliveries and reduced transportation costs. It provides salesmen with information about the availability of products and about prices within minutes. It updates sales statistics continuously. It automatically requisitions replenishments when inventories fall below a given level. The data captured by the computer from the messages it is continually receiving and transmitting give the management a growing fund of timely information.

One interesting application of the Westinghouse computer system is a "cash-management information program" that keeps a running account of the cash flow. All receipts and disbursements of the various Westinghouse divisions are immediately transmitted by teletype to the telecomputer center and recorded in the appropriate accounts. When the balance in any of the corporation's 250 regional bank accounts falls below a preset level, the computer automatically orders a transfer of cash from the central bank account. When the balance in the central account is higher than necessary, the treasury office invests the excess in marketable securities, notifying the computer as it does so. The net result is that the company's management knows the company's cash position at all times and is able to put formerly idle funds to work earning interest.

A device for the graphical display of financial information has been installed at Westinghouse headquarters and is now being tested and "debugged." It will picture for the Westinghouse executives trends in the company's financial operations and will compare financial forecasts with actual accomplishments. The system has important implications for planning by top management. Other applications of the computer to planning are being made at the General Electric Company, the International Business Machines Corporation, the Standard Oil Company (New Jersey) and many other large corporations.

What has occurred in real-time programming up to now is obviously only a prelude to much more far-reaching developments that are likely to follow in the coming years. Let us speculate a bit on the nature of these developments and their possible broad-scale effects on our business and industrial organizations.

One aspect of the organization that is likely to be affected is the degree to which its control is centralized. Over the past 30 years, as enterprises have grown enormously in size, the trend has been toward decentralization of company operations through the setting up of divisions and profit centers. The giant corporations have found, however, that decentralization can be a mixed blessing. It tends to multiply jobs, duplicate functions and establish local goals that may run orthogonally to the objectives of the organization as a whole. It also places a burden on the company's information system by multiplying the need for information at the same time that it disperses information in a multitude of separate files spread through the organization. It may be days or weeks before new information is processed, summarized, transmitted and made available to the people who need it for operations and decisions.

Clearly the computer can help to correct this situation. Data from the many divisions and hierarchical levels of the organization will flow directly into a central computer memory, in the same way that information about hundreds of thousands of inventory items now feeds into Lockheed's automatic data-acquisition system from hundreds of remote

terminals. The computer programs will promptly sort the information, place each item in an appropriate list or report, link it to related information already stored and make the processed information quickly accessible to those who need it for authorized purposes.

Some investigators in this field believe that systems for integrating the company files will eventually reverse the trend toward decentralization. That is a moot question; the centralization of information need not imply the centralization of control. It will surely streamline operations, however, and save the company money. Most important, it will give the company a new coherence and sense of unity, and it will pave the way to further mechanization of the company's activities.

Much of this mechanization may take place within the computer. The further evolution of computer programs may repeat the history of industrialization: in the first phase, the division of labor into easy-to-execute tasks; in the second phase, the delegation of these tasks to machines. The first phase was demonstrated by Adam Smith two centuries ago in *The Wealth of Nations*. Smith observed how the division of labor speeded the manufacture of pins: "One man draws out the wire, another straightens it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a peculiar business, to whiten the pins is another ...and the important business of making a pin is, in this manner, divided into about 18 distinct operations.... I have seen a small manufactory of this kind where...ten persons could make among them upwards of 48,000 pins in a day." Today a single machine, going through much the same process Smith described, turns out several hundred thousand pins per hour.

In the future enactment of this process programs will play the part of machines. Suppose a company has a real-time, time-shared computer that participates as a central instrument of operations. Suppose its body of programming is open-ended, like the OPS system, and is able to grow and assume new functions easily. The routine the computer employs to store away incoming transaction data does the work of a team of file clerks. The routines it has to make this data available on demand to customer representatives and to summarize the data in periodic reports to management are like staff assistants.

The company will be able to expand its work force by hiring employees with the requisite skills, or by extending its real-time computer program, or by a combination of both. Additions and modifications to the program can be kept tentative and flexible until they are judged to perform satisfactorily by human monitors at the consoles. Programs may be refined and made more efficient by a continual policy of replacement and improvement. Over a period of time the computer system will become larger in scope, better in detail and a vital part of the company organization. There will be an intriguing interplay of centripetal and centrifugal forces, tasks for which the computer shows an aptitude being drawn into the body of programming and tasks that are better performed by the human touch or mind drifting outward to the operators at the consoles (and beyond). Ultimately the parallel organizations of people and programs in an enterprise may blend together and appear as one, just as organizations of people and machines have done in the past.

What this means for the future of our economy and society remains to be seen. It appears likely that our organizations and institutions will function more efficiently and smoothly and thus become significantly more productive. As others have remarked, there is no reason to suppose this will result in a glut of goods and services or in massive unemployment, even though job descriptions may change drastically.

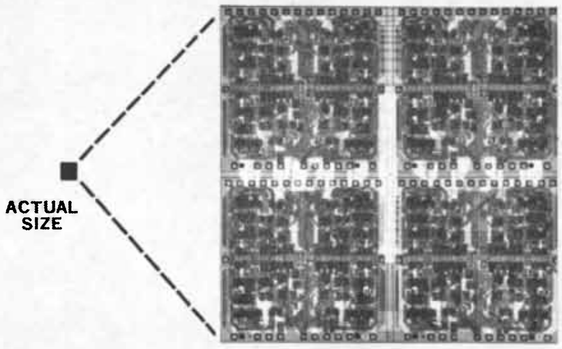
Much has been written about the dangers that may lie in wait for a computerized society: the cult of the machine, overdelegation of our activities to the computer, too much faith in its simplifications and quantifications, the invasion of privacy and individual rights by overzealous programs of industry or government, criminal misuses of the computer. These possibilities are real and should not be waved aside. Computer scientists take them seriously and are today in an uncomfortable position somewhat like that of the nuclear physicists after the discovery of uranium fission.

It should be perfectly clear, however, that the dangers arise from the way man may use the computer, not from the machine itself. The computer remains under human control. The programs of the future will have the character man designs into them, and prevention of abuses is an important part of the design problem.

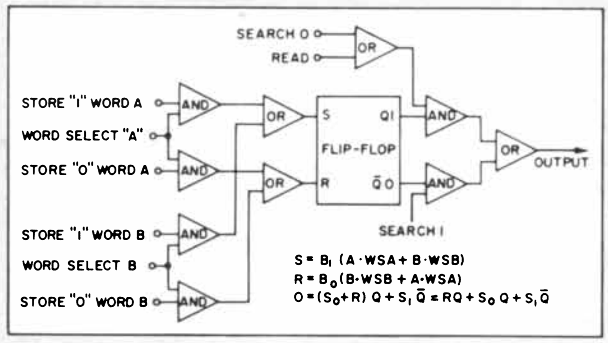
HIGH-SPEED CONTENT ADDRESSABLE MEMORY

A report on Microelectronics from MOTOROLA

ACTUAL SIZE



4 x 4 Array Before Wire Bonding

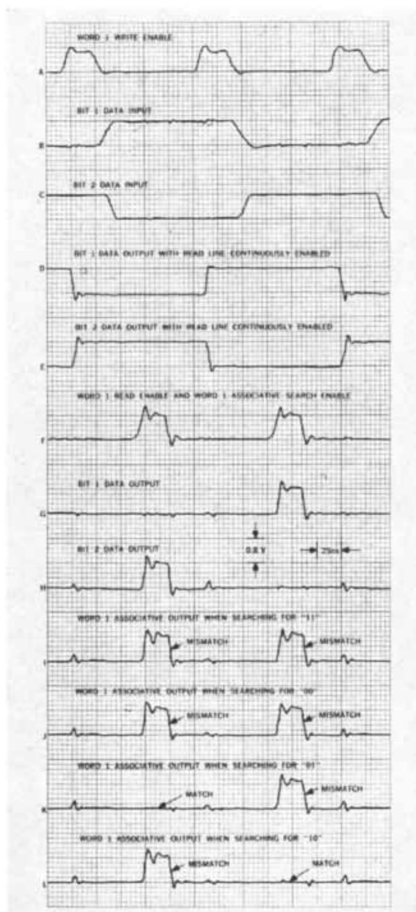


Block Diagram of a Dual Write Associative Memory Bit

Content Addressable Memories (CAM) differ from Random Access Memories (RAM) in that the specific information sought is made accessible by content association rather than by address location. To accomplish this, more logic had to be combined with the storage function in a CAM type memory, as shown by the above logic diagram. High speed semiconductor implementation of this concept becomes more practical with integrated circuit technology than with magnetic approaches because of inherent higher speed, more logic flexibility, simplified peripheral circuitry and the fact that levels are compatible with those in the arithmetic and control sections of the computer.

A CAM chip of a 4 x 4 array is shown in the above photomicrograph. The chip measures 120x120 mil and contains 524 elements. The actual time response of the memory is shown at right. From this it can be seen that the propagation delay from "Write Enable" to "Read and Search 1" or "Search 0" delays are 6 and 2 ns. respectively.

Today integrated CAM memories are operating in the MOTOROLA laboratories, and because of the cost and size reducing potential of large scale integrated circuit technology, this powerful storage element will soon be ready to operate in the next generation of electronic computers.



Various Transient Responses of the "CAM" 2 x 2 Array

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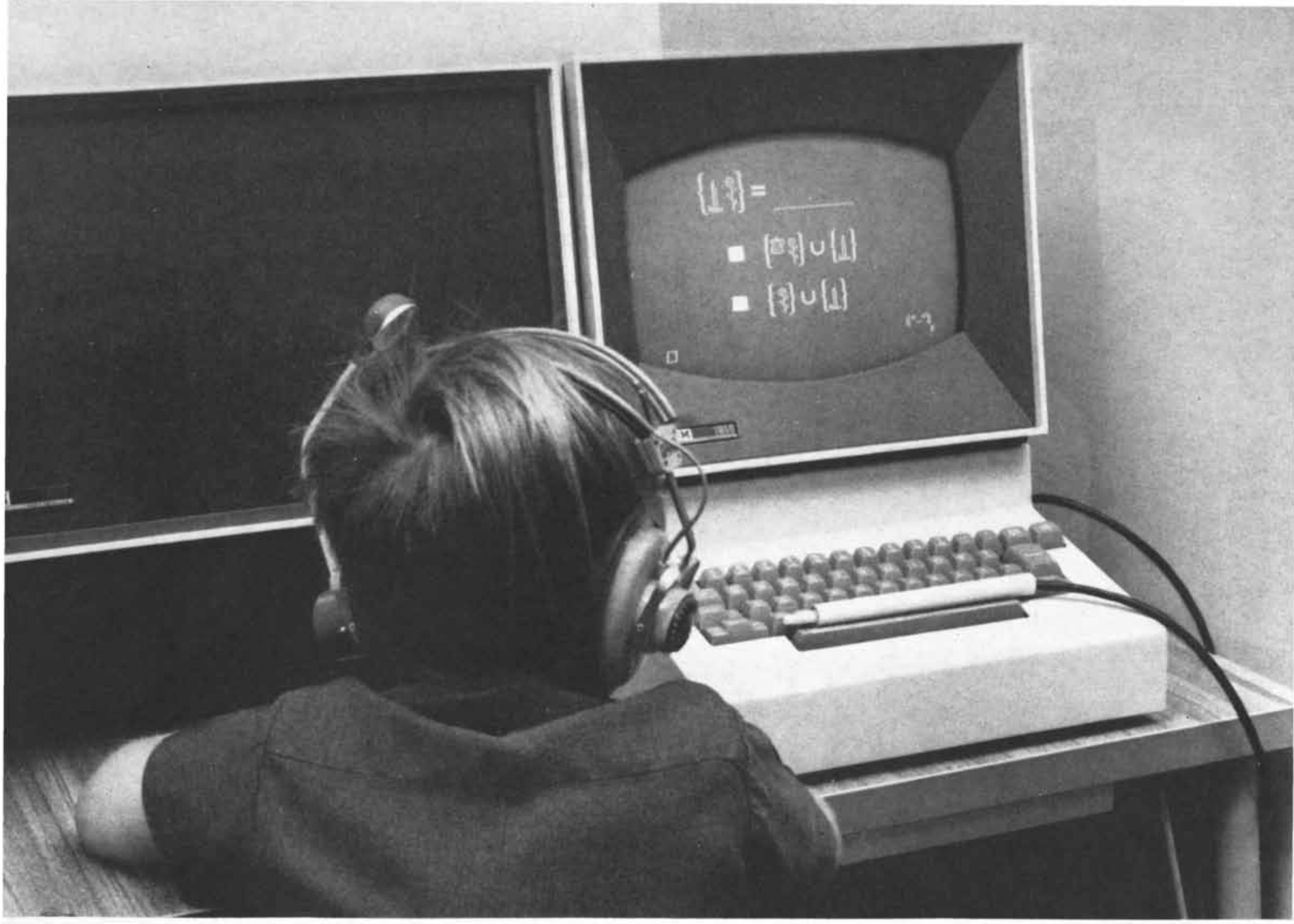
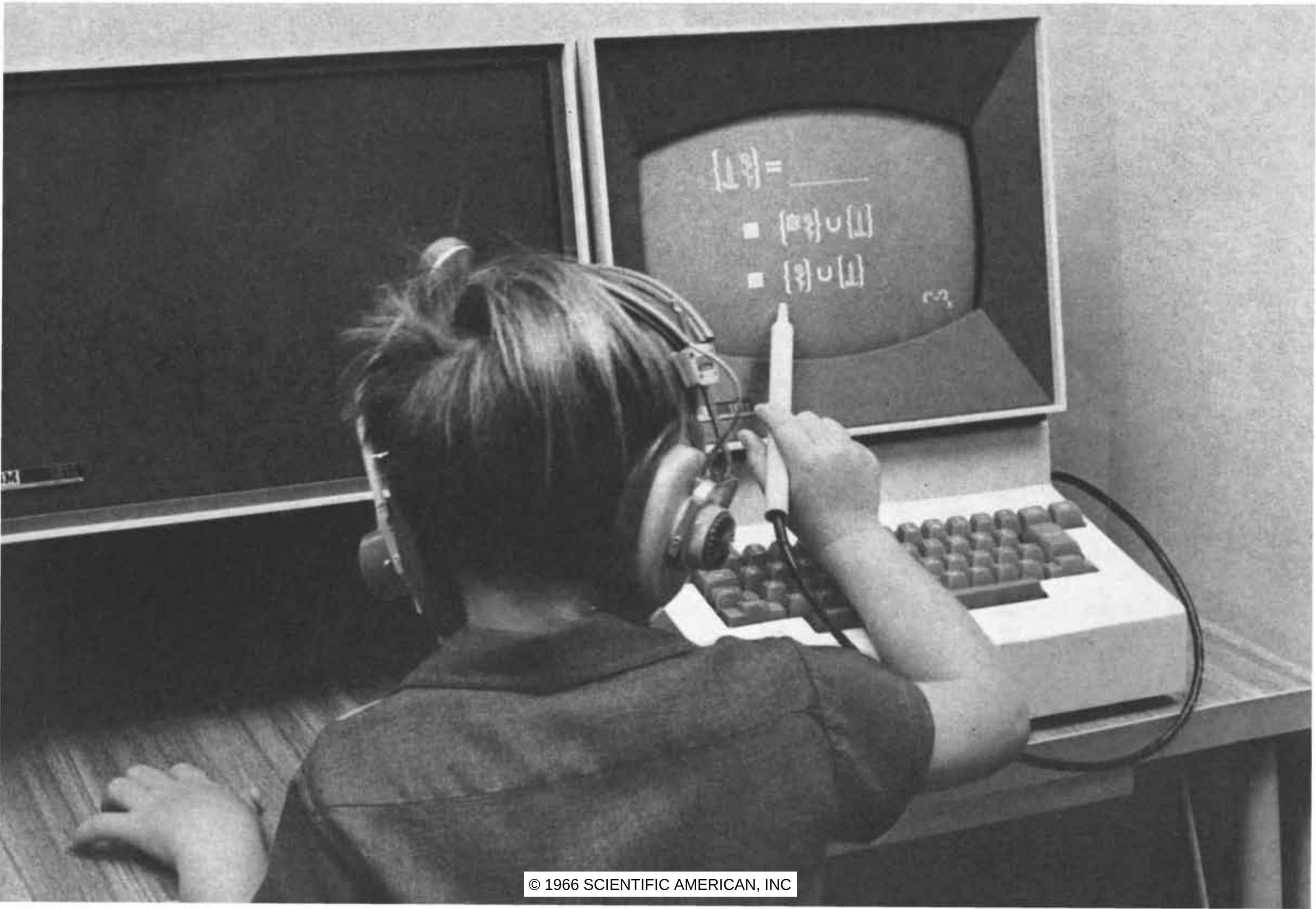




The Uses of Computers in Education

The huge information-processing capacities of computers make it possible to use them to adapt mechanical teaching routines to the needs and the past performance of the individual student

by Patrick Suppes

As other articles in this issue make abundantly clear, both the processing and the uses of information are undergoing an unprecedented technological revolution. Not only are machines now able to deal with many kinds of information at high speed and in large quantities but also it is possible to manipulate these quantities of information so as to benefit from them in entirely novel ways. This is perhaps nowhere truer than in the field of education. One can predict that in a few more years millions of schoolchildren will have access to what Philip of Macedon's son Alexander enjoyed as a royal prerogative: the personal services of a tutor as well-informed and responsive as Aristotle.

The basis for this seemingly extravagant prediction is not apparent in many examinations of the computer's role in education today. In themselves, however, such examinations provide impressive evidence of the importance of computers on the educational scene. As an example, a recent report of the National Academy of Sciences states that by mid-1965 more than 800 computers were in service on the campuses of various American universities and that these institutions spent $175 million for computers that year. The report goes on to forecast that by 1968 the universities' annual budget for computer operations will reach $300 million and that their total investment in computing facilities will pass $500 million.

A similar example is represented by the fact that most colleges of engineering and even many high schools now use computers to train students in computer programming. Perhaps just as important as the imposition of formal course requirements at the college level is the increasingly widespread attitude among college students that a knowledge of computers is a "must" if their engineering or scientific training is to be up to date. Undergraduates of my generation who majored in engineering, for instance, considered a slide rule the symbol of their developing technical prowess. Today being able to program a computer in a standard language such as FORTRAN or ALGOL is much more likely to be the appropriate symbol.

At the graduate level students in the social sciences and in business administration are already making use of computers in a variety of ways, ranging from the large-scale analysis of data to the simulation of an industry. The time is rapidly approaching when a high percentage of all university graduates will have had some systematic training in the use of computers; a significant percentage of them will have had quite sophisticated training. An indication of the growth of student interest in computers is the increase in student units of computer-science instruction we have had at Stanford University over the past four years. Although total enrollment at Stanford increased only slightly during that period, the number of student units rose from 2,572 in 1962–1963 to 5,642 in 1965–1966.

The fact that time-sharing programs are rapidly becoming operational in many university computation centers justifies the forecast of another increase in the impact of computers on the universities [see "Time-sharing on Computers," by R. M. Fano and F. J. Corbató, page 128]. Under time-sharing regimes a much larger number of students can be given direct "on line" experience, which in itself is psychologically attractive and, from the practical viewpoint, facilitates deeper study of the use of computers. There is still another far from trivial way in which the computer serves the interests of education: The large school system that does not depend on computers for many administrative and service functions is today the exception rather than the rule.

The truly revolutionary function of computers in education, however, lies in the novel area of computer-assisted instruction. This role of the computer is scarcely implemented as yet but, assuming the continuation of the present pace of technological development, it cannot fail to have profound effects in the near future. In this article I shall describe some experiments in computer-assisted instruction that are currently being conducted at levels ranging from the comparatively simple to the quite complex and then examine some unsuspected problems that these experiments have revealed. First, however, the reader deserves an explanation of why computer-assisted instruction is considered desirable at all.

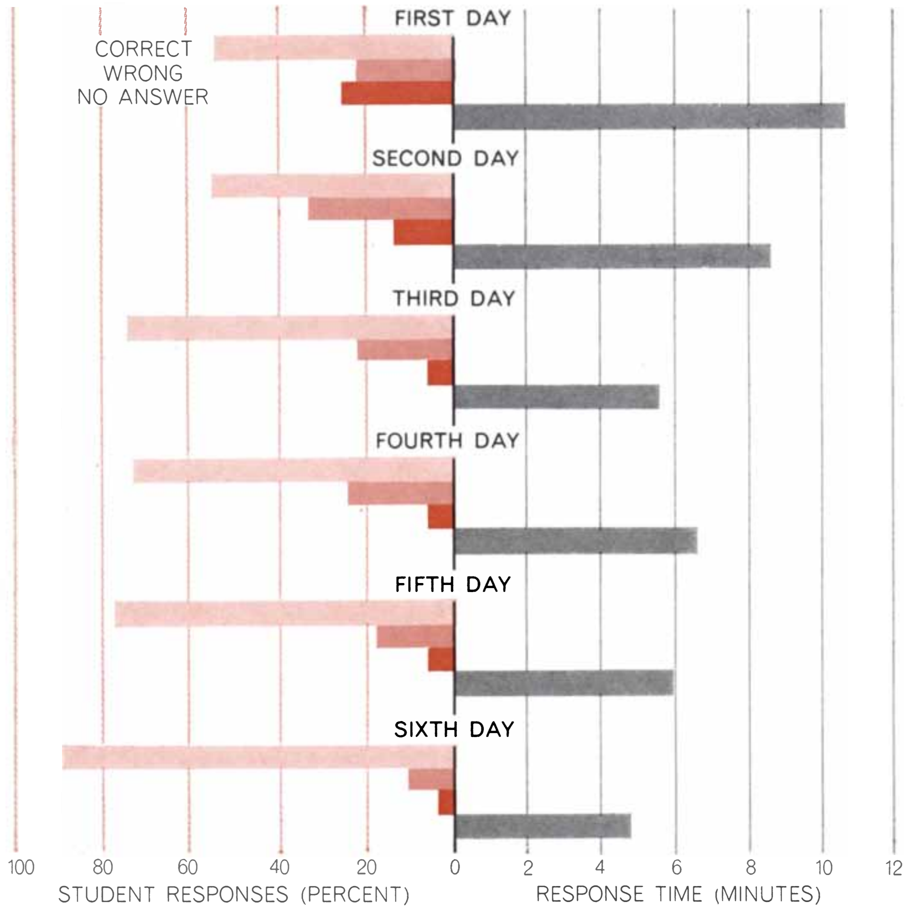
The single most powerful argument

COMPUTER-ASSISTED INSTRUCTION in elementary arithmetic is illustrated in the photographs on the opposite page. A first-grade pupil, receiving "readiness" work preparatory to instruction in addition, is shown two possible answers to a question implicit in the symbols occupying the top line of a cathode-ray-tube display. As he watches (*top photograph*), his earphones carry a verbal message asking him to select from the symbolic statements of union shown in the second and third lines of the display the one that is identical with the equation shown in the top line. The pupil signals his choice (*bottom photograph*) by pointing to the statement he prefers with machine's light pen; the computer then records the answer.

for computer-assisted instruction is an old one in education. It concerns the advantages, partly demonstrated and partly conjectured, of individualized instruction. The concept of individualized instruction became the core of an explicit body of doctrine at the end of the 19th century, although in practice it was known some 2,000 years earlier in ancient Greece. For many centuries the education of the aristocracy was primarily tutorial. At the university level individualized tutorial instruction has been one of the glories of Oxford and Cambridge. Modern criticisms of the method are not directed at its intrinsic merit but rather at its economic inefficiency. It is widely agreed that the more an educational curriculum can adapt in a unique fashion to individual learners—each of whom has his own characteristic initial ability, rate and even "style" of learning—the better the chance is of providing the student with a successful learning experience.

The computer makes the individualization of instruction easier because it can be programmed to follow each student's history of learning successes and failures and to use his past performance as a basis for selecting the new problems and new concepts to which he should be exposed next. With modern information-storage devices it is possible to store both a large body of curriculum material and the past histories of many students working in the curriculum. Such storage is well within the capacity of current technology, whether the subject is primary school mathematics, secondary school French or elementary statistics at the college level. In fact, the principal obstacles to computer-assisted instruction are not technological but pedagogical: how to devise ways of individualizing instruction and of designing a curriculum that are suited to individuals instead of groups. Certain obvious steps that take account of different rates of learning can be made with little difficulty; these are the main things that have been done so far. We have still, however, cut only a narrow path into a rich jungle of possibilities. We do not have any really clear scientific idea of the extent to which instruction can be individualized. It will probably be some time before a discipline of such matters begins to operate at anything like an appropriately deep conceptual level.

A second important aspect of computers in education is closer in character to such familiar administrative functions as routine record-keeping. Before the advent of computers it was extremely difficult to collect systematic data on how children succeed in the process of learning a given subject. Evaluative tests of achievement at the end of learning have (and will undoubtedly continue to have) a place both in the process of classifying students and in the process of comparing different curriculum approaches to the same subject. Nonetheless, such tests remain blunt and insensitive instruments, particularly with respect to detailed problems of instruction and curriculum revision. It is not possible on the basis of poor results in a test of children's mastery of subtraction or of irregular verbs in French to draw clear inferences about ways to improve the curriculum. A computer, on the other hand, can provide daily information about how students are performing on each part of the curriculum as it is presented, making it possible to evaluate not only individual pages but also individual exercises. This use of computers will have important consequences for all students in the immediate future. Even if students are not themselves receiving computer-assisted instruction, the results of such instruction will certainly be used to revise and improve ordinary texts and workbooks.



IMPROVEMENT IN LEARNING is one evident result of drill and practice. The graph summarizes the results of a six-day drill on the commutative, associative and distributive laws of arithmetic. The computer program covered 48 concepts; each day's session presented 24 problems. Two days' drill therefore reviewed all 48 concepts, although no identical problems were presented during the six days. By the last day student responses were more than 90 percent correct and the speed of reply was twice what it was at the start.

Let me now take up some of the work in computer-assisted instruction we have been doing at Stanford. It should be emphasized that similar work is in progress at other centers, including the University of Illinois, Pennsylvania State University, the University of Pittsburgh, the University of Michigan, the University of Texas, Florida State University and the University of California at Santa Barbara, and within such companies as the International Business Machines Corporation, the Systems Development Corporation and Bolt, Beranek and Newman. This list is by no means exhaustive. The work at these various places runs from a primary emphasis on the development of computer hardware to the construction of short courses in subjects ranging from physics to typing. Although all these efforts, including ours at Stanford, are

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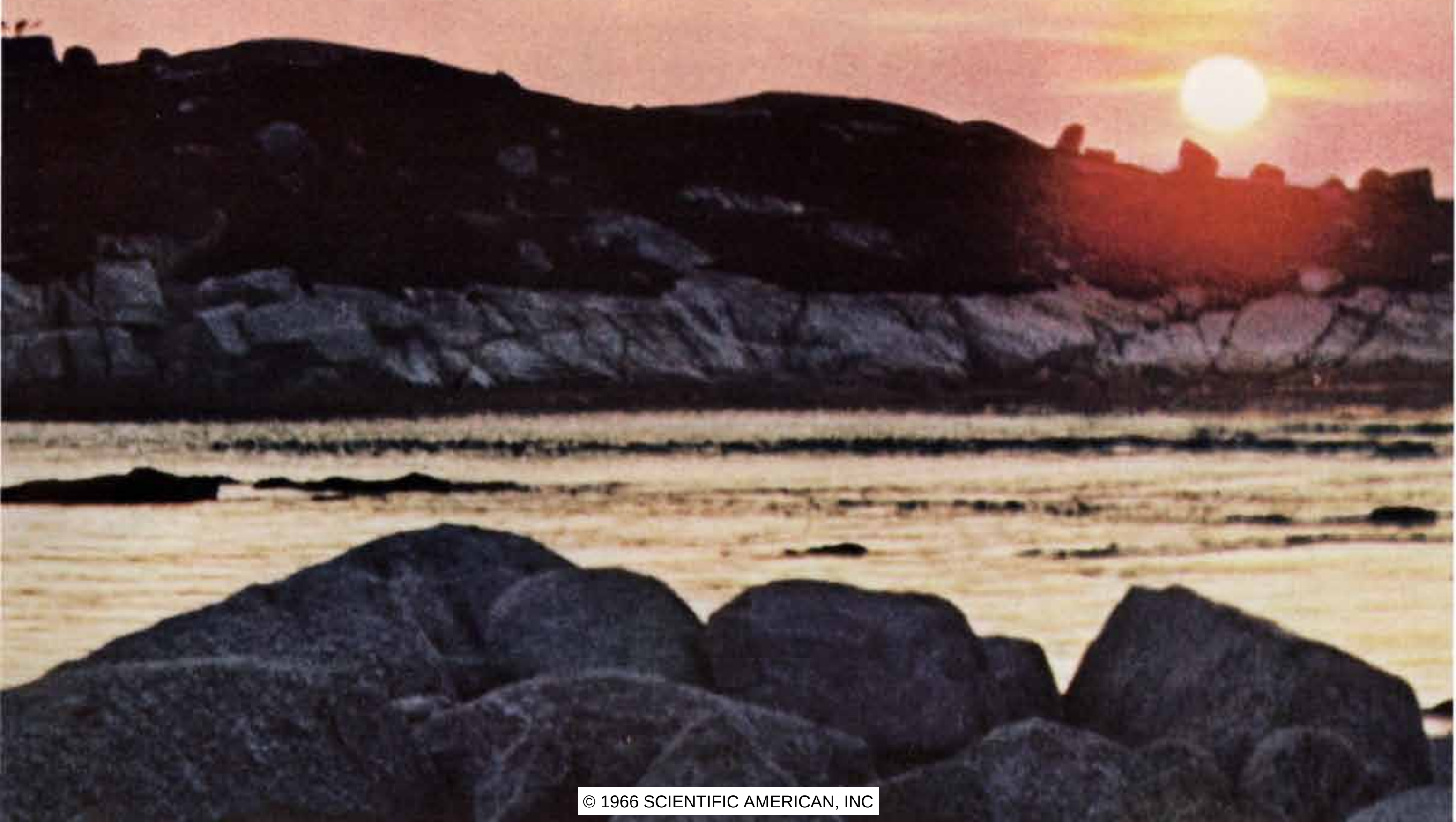

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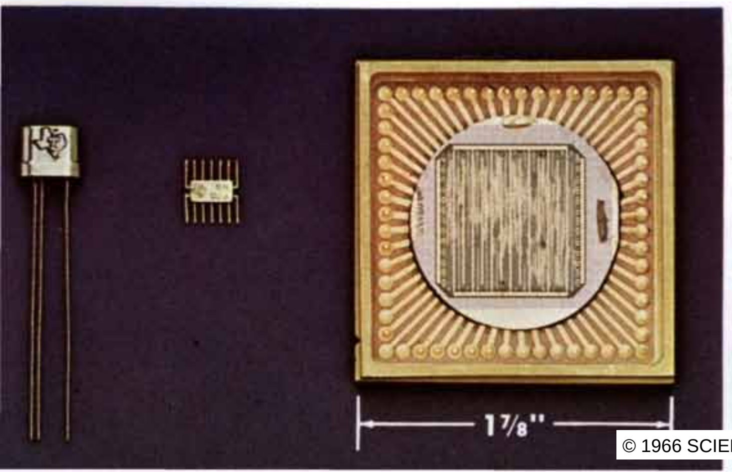
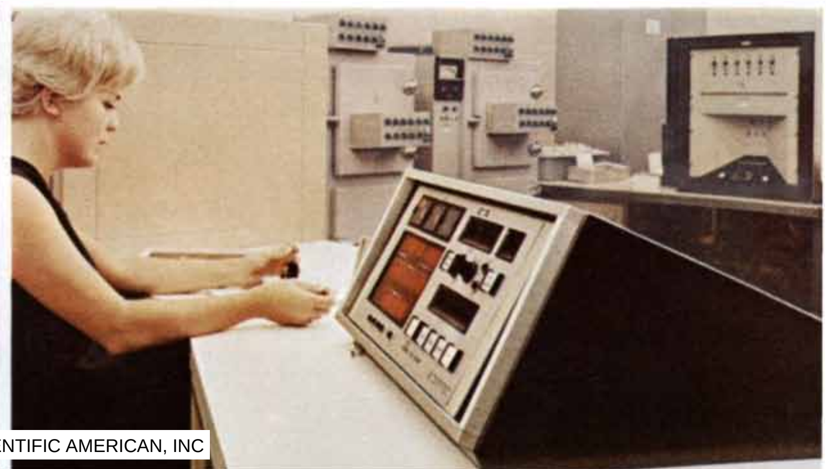


Component and Circuit Tester



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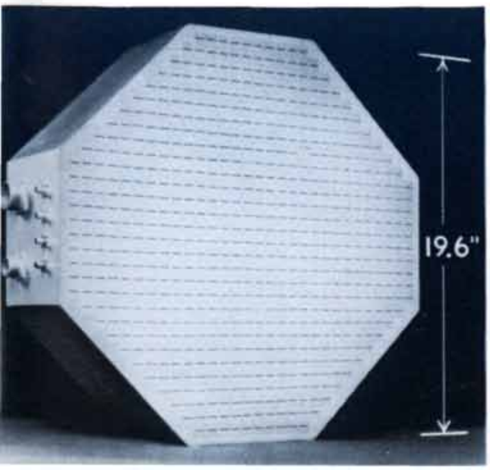
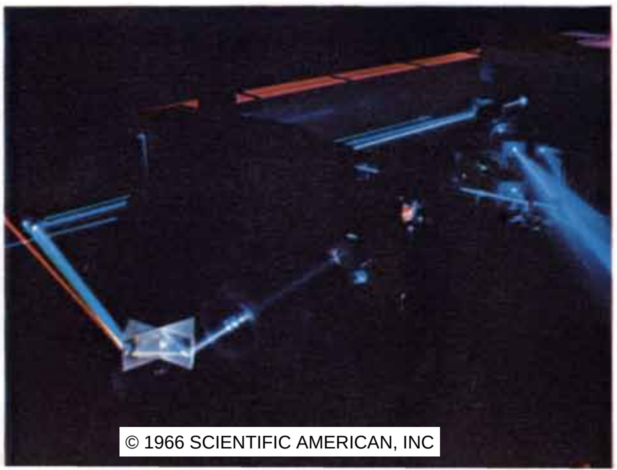
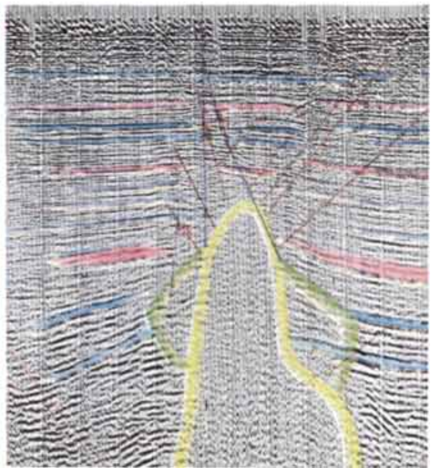
MERA Radar



Laser Display



Subsea Salt Dome



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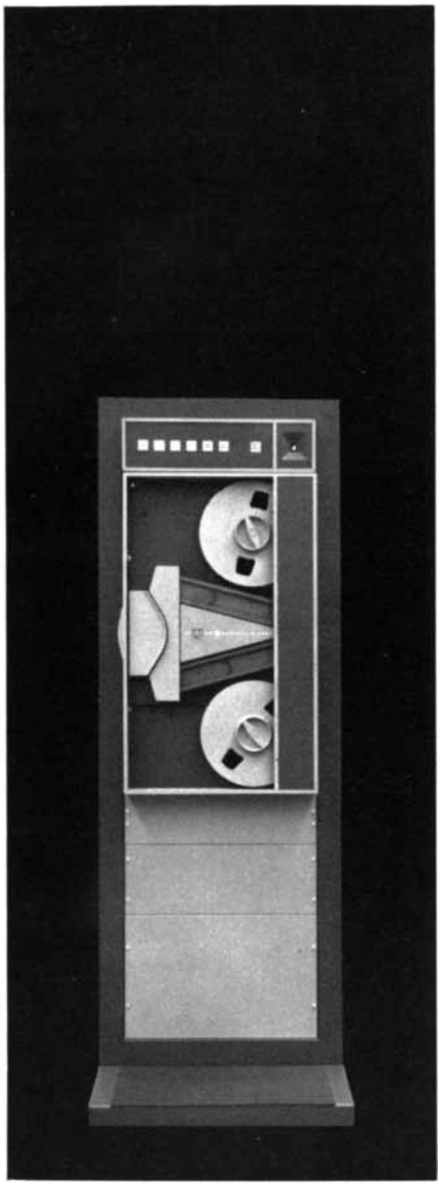

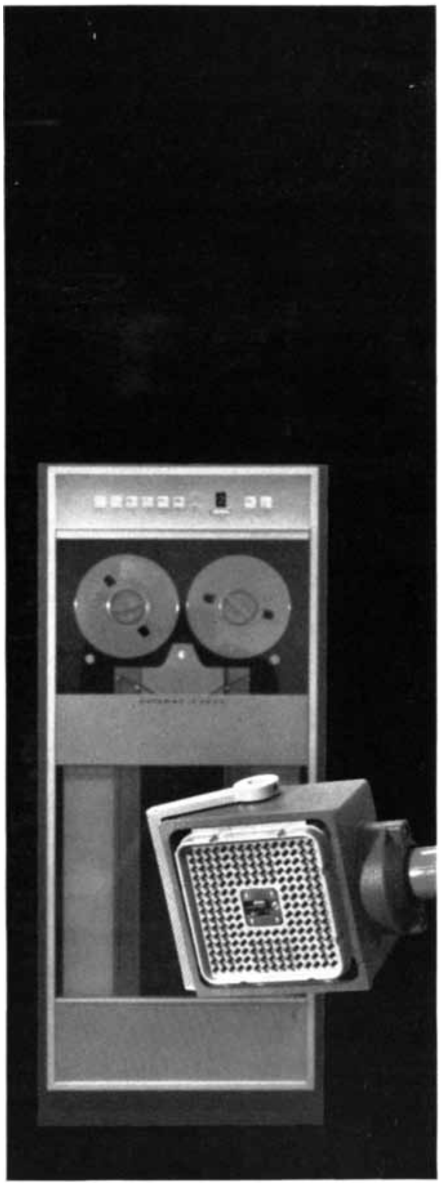

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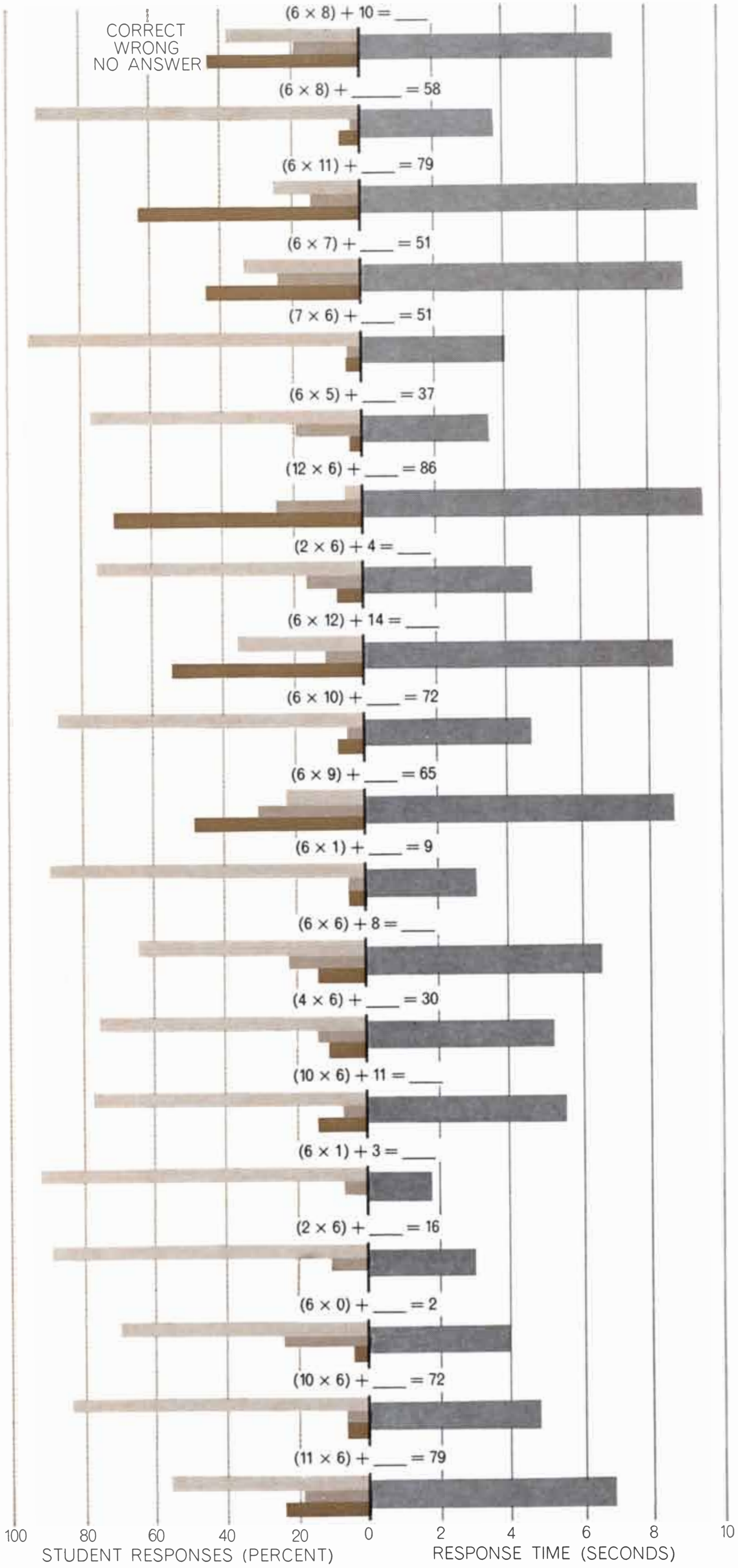
still in the developmental stage, the instruction of large numbers of students at computer terminals will soon (if academic and industrial soothsayers are right) be one of the most important fields of application for computers.

At Stanford our students are mainly at the elementary school level; the terminals they use, however, are also suitable for secondary school and university students. At each terminal there is a visual device on which the student may view displays brought up from the computer memory as part of the instruction program. A device that is coming into wide use for this purpose is the cathode ray tube; messages can be generated directly by the computer on the face of the tube, which resembles a television screen. Mounted with the cathode ray tube is a typewriter keyboard the student can use to respond to problems shown on the screen. At some additional cost the student can also have a light pen that enables him to respond directly by touching the pen to the screen instead of typing on the keyboard. Such a device is particularly useful for students in the lowest elementary grades, although when only single-digit numerical responses or single-character alphabetical ones are required, the use of a keyboard is quite easy even for kindergarten children to learn.

After the display screen and the keyboard the next most important element at a terminal is the appropriate sound device. Presenting spoken messages to students is desirable at all educational levels, but it is particularly needed for younger children. It would be hard to overemphasize the importance of such spoken messages, programmed to be properly sensitive to points at which the student may encounter difficulty in learning. Such



COMPUTER SUMMARY of drill results makes possible the analysis essential for assessment and revision of various study curriculums. The results of 37 children's replies to 20 questions designed to test elementary arithmetic skills are summarized graphically in this illustration. The most troublesome question proved to be No. 7; not only did it take the most time to answer but also 26 students failed to answer it at all and only two answered it correctly. Although question No. 9 is the exact reverse of question No. 7, it received 13 correct answers. Evidently obtaining an unknown quantity by subtraction is harder than obtaining one by addition, and the students found it harder to multiply 12 by 6 than to multiply 6 by 12.

messages are the main help a good tutor gives his pupil; they are the crucial missing element in noncomputerized teaching machines. All of us have observed that children, especially the younger ones, learn at least as much by ear as they do by eye. The effectiveness of the spoken word is probably stronger than any visual stimulus, not only for children but also most of the time for adults. It is particularly significant that elementary school children, whose reading skills are comparatively undeveloped, comprehend rather complicated spoken messages.

A cathode ray tube, a keyboard and a loudspeaker or earphones therefore constitute the essential devices for computer-assisted instruction. Additional visual displays such as motion pictures or line drawings can also be useful at almost all levels of instruction. Ordinary film projectors under computer control can provide such displays.

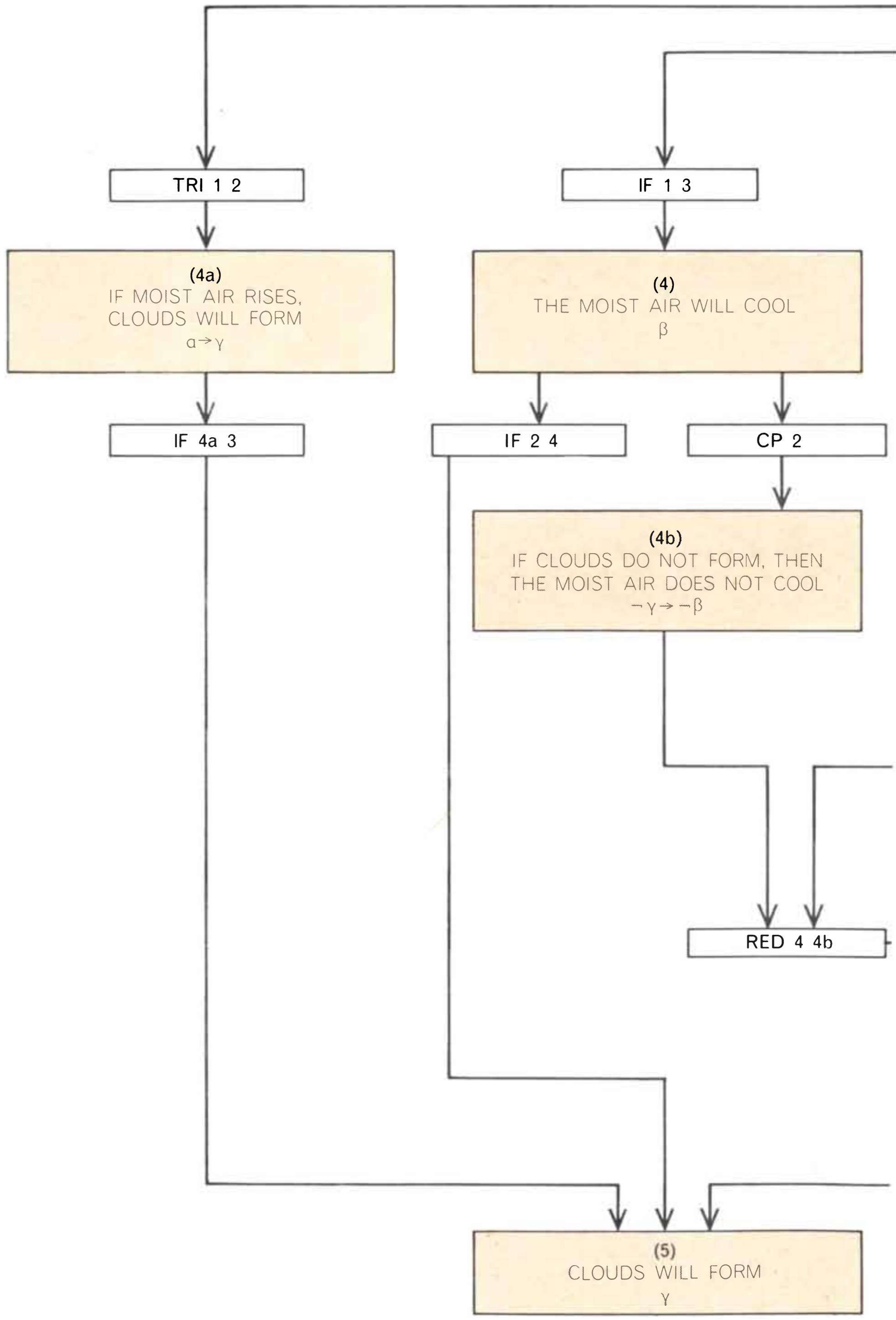
So far three levels of interaction between the student and the computer program have received experimental attention. At the most superficial level (and accordingly the most economical

GLOSSARY

- α MOIST AIR RISES
- β MOIST AIR COOLS OR WILL COOL
- γ CLOUDS WILL FORM
- → FORMAL IMPLICATION
- ¬ NOT

RULES OF INFERENCE

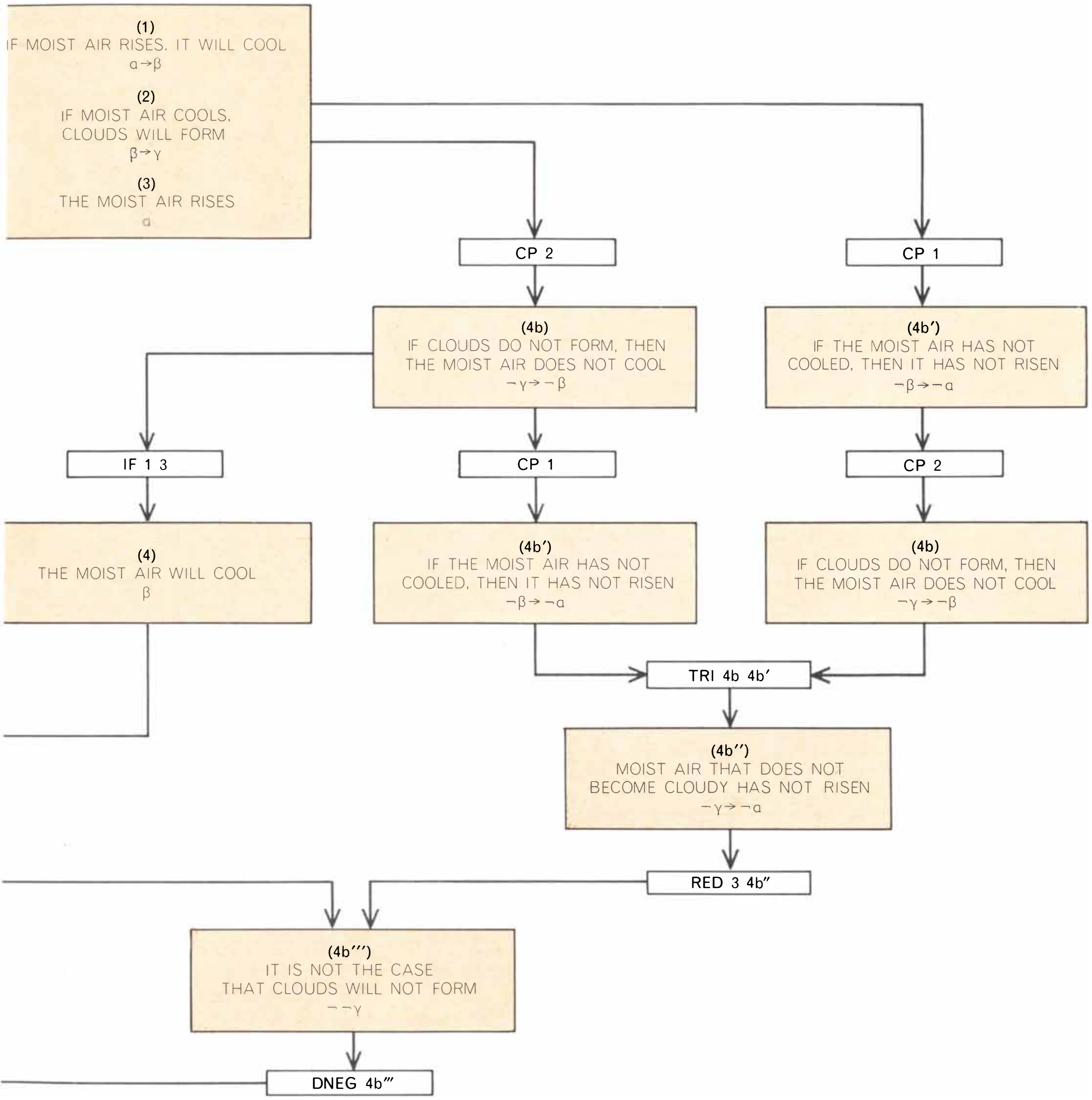
- TRI TRANSIVITY OF IMPLICATION (FROM X→Y AND Y→Z, DERIVE X→Z)
- IF MODUS PONENS (FROM X→Y AND X, DERIVE Y)
- CP CONTRAPOSITIVE (FROM X→Y, DERIVE ¬Y→¬X)
- DNEG DOUBLE NEGATION (FROM ¬¬X, DERIVE X)
- RED CONTRADICTION OF CONSEQUENT (FROM Y AND X→¬Y, DERIVE ¬X)



TUTORIAL EXERCISE in mathematical logic is an example of a more complex variety of computer-assisted instruction. The student may proceed from a set of given hypotheses (*top*) to a given conclusion (*bottom*) by any one of several routes. Each of the illustrated downward paths represents a legitimate logical attack on the problem and each constitutes a unique sequence of inferences (*see legend and statements in logical notation below each of the numbered verbal statements*). Ideally a tutorial computer program will show no preference for one path over another but will check the soundness of each step along any path and tell the student if he makes any mistakes in logic.

one) are "drill and practice" systems. Instruction programs that fall under this heading are merely supplements to a regular curriculum taught by a teacher. At Stanford we have experimented a great deal with elementary school mathematics at the drill-and-practice level, and I shall draw on our experience for examples of what can be accomplished with this kind of supplementation of a regular curriculum by computer methods.

Over the past 40 years both pedagogical and psychological studies have provided abundant evidence that students need a great deal of practice in order to master the algorithms, or basic procedures, of arithmetic. Tests have shown that the same situation obtains for students learning the "new math." There seems to be no way to avoid a good deal of practice in learning to execute the basic algorithms with speed and accuracy. At the elementary level the most important way in which computer-assisted instruction differs from traditional methods of providing practice is that we are in no sense committed to giving each child the same set of problems, as would be the case if textbooks or other written materials were used. Once a number



```
PLEASE TYPE YOUR NAME

ROBERT VALENTINE

DRILL NUMBER 604032

L.C.M.  MEANS  LEAST COMMON MULTIPLE

___ IS THE L.C.M. OF  4 AND  9

TIME IS UP

_36 IS THE L.C.M. OF  4 AND  9

_23 IS THE L.C.M. OF 12 AND  8

WRONG

_24 IS THE L.C.M. OF 12 AND  8

_1_ IS THE L.C.M. OF 15 AND 10

WRONG

___ IS THE L.C.M. OF 15 AND 10

TIME IS UP, ANSWER IS 30

_30 IS THE L.C.M. OF 15 AND 10

_60 IS THE L.C.M. OF 12 AND 30

_12 IS THE L.C.M. OF  2,  4, AND  6



_40 IS THE L.C.M. OF  8, 10, AND  5

S. FOR SUMMARY S.

                NUMBER    PERCENT
CORRECT           14         70
WRONG              5         25
TIMEOUT            1          5
70% CORRECT IN BLOCK, 70% OVERALL TO DATE
GOOD BYE, O FEARLESS DRILL TESTER.
TEAR OFF ON DOTTED LINE

.......................................................
```

DRILL-AND-PRACTICE EXERCISE, shown in abbreviated form, is typical of a simple computer-assisted instruction program that is designed to be responsive to the needs of individual students. The illustrated exercise is one of five that differ in their degree of difficulty; when the student types his name (*color*), the exercise best suited to him on the basis of computer-memory records of his previous performance is selected automatically. The first three questions and answers exemplify the ways in which the computer is programmed to deal with various shortcomings. The student fails to answer the first question within the allotted 10-second time limit; the computer therefore prints TIME IS UP and repeats the question, which the student then answers correctly (*color*). A wrong answer to the next question causes the computer to announce the error and repeat the question automatically; a second chance again elicits a correct answer. A wrong answer to the third question is compounded by failure to respond to the reiterated question within the time limit. Because this question has now drawn two unsatisfactory responses the automatic TIME IS UP statement is followed by a printing of the correct answer. The question is now repeated for a third and last time. Whether or not the student elects to copy the correct answer (he does so in this instance), the computer automatically produces the next question. Only six of the 20 questions that compose the drill are shown in the example. After the student's last answer the computer proceeds to print a summary of the student's score for the drill as well as his combined average for this and earlier drills in the same series. The drill-and-practice exercise then concludes with a cheery farewell to the student and an instruction to tear off the teletype tape.

of study "tracks," representing various levels of difficulty, have been prepared as a curriculum, it is only a matter of computer programming to offer students exercises of varying degrees of difficulty and to select the appropriate level of difficulty for each student according to his past performance.

In the program we ran in elementary grades at schools near Stanford during the academic year 1965–1966 five levels of difficulty were programmed for each grade level. A typical three-day block of problems on the addition of fractions, for example, would vary in the following way. Students at the lowest level (Level 1) received problems involving only fractions that had the same denominator in common. On the first two days levels 2 and 3 also received only problems in which the denominators were the same. On the third day the fraction problems for levels 2 and 3 had denominators that differed by a factor of 2. At Level 4 the problems had denominators that differed by a factor of 2 on the first day. At Level 5 the denominators differed by a factor of 3, 4, 5 or 6 on the first day. Under the program the student moved up and down within the five levels of difficulty on the basis of his performance on the previous day. If more than 80 percent of his exercises were done correctly, he moved up a level. If fewer than 60 percent of the exercises were done correctly, he moved down a level. The selection of five levels and of 80 and 60 percent has no specific theoretical basis; they are founded on practical and pedagogical intuition. As data are accumulated we expect to modify the structure of the curriculum.

Our key effort in drill-and-practice systems is being conducted in an elementary school (grades three through six) a few miles from Stanford. The terminals used there are ordinary teletype machines, each connected to our computer at Stanford by means of individual telephone lines. There are eight teletypes in all, one for each school classroom. The students take turns using the teletype in a fixed order; each student uses the machine once a day for five to 10 minutes. During this period he receives a number of exercises (usually 20), most of which are devoted to a single concept in the elementary school mathematics curriculum. The concept reviewed on any given day can range from ordinary two-digit addition to intuitive logical inference. In every case the teacher has already presented the concept and the pupil has had some classroom practice; the computer-assisted drill-and-practice work therefore supplements the teacher's instruction.

The machine's first instruction—PLEASE TYPE YOUR NAME—is already on the teletype paper when the student begins his drill. The number of characters required to respond to this instruction is by far the longest message the elementary student ever has to type on the keyboard, and it is our experience that every child greatly enjoys learning how to type his own name. When the name has been typed, the pupil's record is looked up in the master file at the computer and the set of exercises he is to receive is determined on the basis of his performance the previous day. The teletype now writes, for example, DRILL 604032. The first digit (6) refers to the grade level, the next two digits (04) to the number of the concept in the sequence of concepts being reviewed during the year, the next two digits (03) to the day in terms of days devoted to that concept (in this case the third day devoted to the fourth concept) and the final digit (2) to the level of difficulty on a scale ranging from one to five.

The real work now begins. The computer types out the first exercise [*see illustration on opposite page*]. The carriage returns to a position at which the pupil should type in his answer. At this point one of three things can happen. If the pupil types the correct answer, the computer immediately types the second exercise. If the pupil types a wrong answer, the computer types WRONG and repeats the exercise without telling the pupil the correct answer. If the pupil does not answer within a fixed time (in most cases 10 seconds), the computer types TIME IS UP and repeats the exercise. This second presentation of the exercise follows the same procedure regardless of whether the pupil was wrong or ran out of time on the first presentation. If his answer is not correct at the second presentation, however, the correct answer is given and the exercise is typed a third time. The pupil is now expected to type the correct answer, but whether he does or not the program goes on to the next exercise. As soon as the exercises are finished the computer prints a summary for the student showing the number of problems correct, the number wrong, the number in which time ran out and the corresponding percentages. The pupil is also shown his cumulative record up to that point, including the amount of time he has spent at the terminal.

A much more extensive summary of student results is available to the teacher. By typing in a simple code the teacher can receive a summary of the work by the class on a given day, of the class's work on a given concept, of the work of any pupil and of a number of other descriptive statistics I shall not specify here. Indeed, there are so many questions about performance that can be asked and that the computer can answer that teachers, administrators and supervisors are in danger of being swamped by more summary information than they can possibly digest. We are only in the process of learning what summaries are most useful from the pedagogical standpoint.

A question that is often asked about drill-and-practice systems is whether we have evidence that learning is improved by this kind of teaching. We do not have all the answers to this complex question, but preliminary analysis of improvement in skills and concepts looks impressive when compared with the records of control classes that have not received computer-assisted instruction. Even though the analysis is still under way, I should like to cite one example that suggests the kind of improvement that can result from continued practice, even when no explicit instructions are given either by the teacher or by the computer program.

During the academic year 1964–1965 we noticed that some fourth-grade pupils seemed to have difficulty changing rapidly from one type of problem format to another within a given set of exercises. We decided to test whether or not this aspect of performance would improve with comparatively prolonged practice. Because we were also dissatisfied with the level of performance on problems involving the fundamental commutative, associative and distributive laws of arithmetic, we selected 48 cases from this domain.

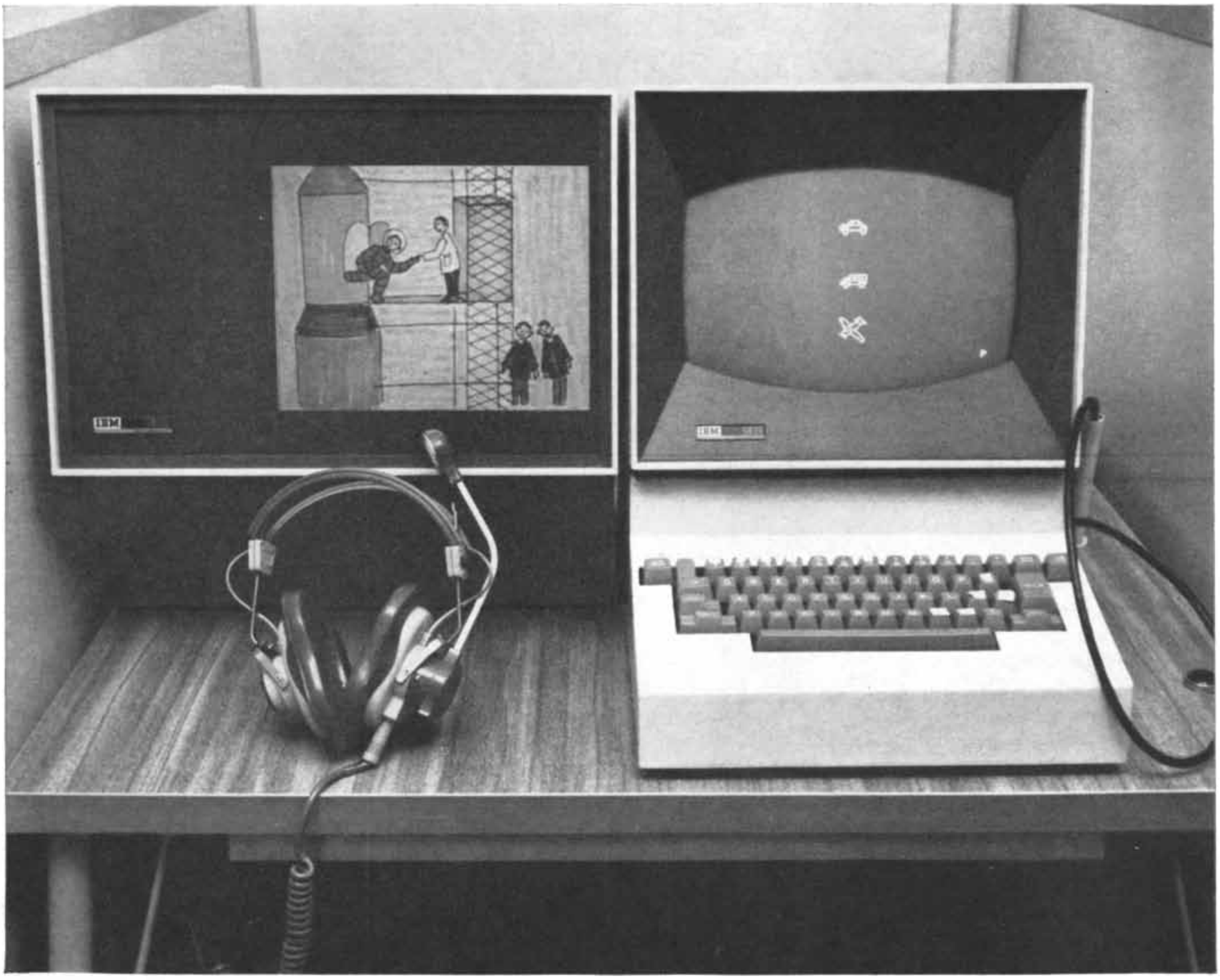
For a six-day period the pupils were cycled through each of these 48 types of exercise every two days, 24 exercises being given each day [*see illustration on page 208*]. No specific problem was repeated; instead the same problem types were encountered every two days on a random basis. The initial performance was poor, with an average probability of success of .53, but over the six-day period the advance in performance was marked. The proportion of correct answers increased and the total time taken to complete the exercises showed much improvement (diminishing from an average of 630 seconds to 279 seconds). Analysis of the individual data showed that every pupil in the class had advanced both in the proportion of correct responses and in the reduction of the time required to respond.

The next level of interaction of the pupil and the computer program is made up of "tutorial" systems, which are more complex than drill-and-practice systems. In tutorial systems the aim is to take over from the classroom teacher the main responsibility for instruction. As an example, many children who enter the first grade cannot properly use the words "top" and "bottom," "first" and "last" and so forth, yet it is highly desirable that the first-grader have a clear understanding of these words so that he can respond in unequivocal fashion to instructions containing them. Here is a typical tutorial sequence we designed to establish these concepts: 1. The child uses his light pen to point to the picture of a familiar object displayed on the cathode-ray-tube screen. 2. The child puts the tip of his light pen in a small square box displayed next to the picture. (This is the first step in preparing the student to make a standard response to a multiple-choice exercise.) 3. The words FIRST and LAST are introduced. (The instruction here is spoken rather than written; FIRST and LAST refer mainly to the order in which elements are introduced on the screen from left to right.) 4. The words TOP and BOTTOM are introduced. (An instruction to familiarize the child with the use of these words might be: PUT YOUR LIGHT PEN ON THE TOY TRUCK SHOWN AT THE TOP.) 5. The two concepts are combined in order to select one of several things. (The instruction might be: PUT YOUR LIGHT PEN ON THE FIRST ANIMAL SHOWN AT THE TOP.)

With such a tutorial system we can individualize instruction for a child entering the first grade. The bright child of middle-class background who has gone to kindergarten and nursery school for three years before entering the first grade and has a large speaking vocabulary could easily finish work on the concepts I have listed in a single 30-minute session. A culturally deprived child who has not attended kindergarten may need as many as four or five sessions to acquire these concepts. It is important to keep the deprived child from developing a sense of failure or defeat at the start of his schooling. Tutorial "branches" must be provided that move downward to very simple presentations, just as a good tutor will use an increasingly simplified approach when he realizes that his pupil is failing to understand what is being said. It is equally important that a tutorial program have enough flexibility to avoid boring a bright child with repetitive exercises he already understands. We have found it best that each pupil progress from one concept in the curriculum to another only after he meets a reasonably stiff criterion of performance. The rate at which the brightest children advance may be five to 10 times faster than that of the slowest children.

In discussing curriculum materials one commonly distinguishes between "multiple-choice responses" and "constructed responses." Multiple-choice exercises usually limit the student to three, four or five choices. A constructed response is one that can be selected by the student from a fairly large set of possibilities. There are two kinds of constructed response: the one that is uniquely determined by the exercise and the one that is not. Although a good part of our first-grade arithmetic program allows constructed responses, almost all the responses are unique. For example, when we ask for the sum of 2 plus 3, we expect 5 as the unique response. We have, however, developed a program in mathematical logic that allows constructed responses that are not unique. The student can make any one of several inferences; the main function of the computer is to evaluate the validity of the inference he makes. Whether or not the approach taken by the student is a wise one is not indicated until he has taken at least one step in an attempt to find a correct derivation of the required conclusion. No two students need find the same proof; the tutorial program is designed to accept any proof that is valid [*see illustration on pages 214 and 215*]. When the student makes a mistake, the program tells him what is wrong with his response; when he is unable to take another step, the program gives him a hint.

It will be evident from these examples that well-structured subjects such as reading and mathematics can easily be handled by tutorial systems. At present they are the subjects we best understand how to teach, and we should be able to use computer-controlled tutorial systems to carry the main load of teaching such subjects. It should be empha-



ESSENTIAL COMPONENTS that allow interaction of computer and student are grouped at this terminal console. The cathode ray tube (*right*) replaces the earlier teletypewriter roll as a more flexible means of displaying computer instructions and questions. Earphones or a loudspeaker reproduce spoken words that are particularly important in primary school instruction. Students may respond to instructions by use of the terminal's keyboard or by use of a light pen (*extreme right*); programs that will enable the computer to receive and respond to the student's spoken words are under study. Supplemental displays are shown on the screen at left.

sized, however, that no tutorial program designed in the near future will be able to handle every kind of problem that arises in student learning. It will remain the teacher's responsibility to attempt the challenging task of helping students who are not proceeding successfully with the tutorial program and who need special attention.

Thus a dual objective may be achieved. Not only will the tutorial program itself be aimed at individualized instruction but also it will free the teacher from many classroom responsibilities so that he will have time to individualize his own instructional efforts. At Stanford we program into our tutorial sessions an instruction to the computer that we have named TEACHER CALL. When a student has run through all branches of a concept and has not yet met the required criterion of performance, the computer sends a teacher call to the proctor station. The teacher at the proctor station then goes to the student and gives him as much individualized instruction as he needs.

At the third and deepest level of student-computer interaction are systems that allow a genuine dialogue between the student and the program. "Dialogue systems" exist only as elementary prototypes; the successful implementation of such systems will require the solving of two central problems. The first may be described as follows: Suppose in a program on economic theory at the college level the student types the question: WHY ARE DEMAND CURVES ALWAYS CONVEX WITH RESPECT TO THE ORIGIN? It is difficult to write programs that will recognize and provide answers to questions that are so broad and complex, yet the situation is not hopeless. In curriculum areas that have been stable for a long time and that deal with a clearly bounded area of subject matter, it is possible to analyze the kinds of questions students ask; on the basis of such an analysis one can make considerable progress toward the recognition of the questions by the computer. Nonetheless, the central intellectual problem cannot be dodged. It is not enough to provide information that will give an answer; what is needed is an ability on the part of the computer program to recognize precisely what question has been asked. This is no less than asking the computer program to understand the meaning of a sentence.

The second problem of the dialogue system is one that is particularly critical with respect to the teaching of elementary school children. Here it is essential that the computer program be able to recognize the child's spoken words. A child in the first grade will probably not be able to type even a simple question, but he can voice quite complex ones. The problem of recognizing speech adds another dimension to the problem of recognizing the meaning of sentences.

In giving an example of the kind of dialogue system we are currently developing at Stanford I must emphasize that the program I am describing (which represents an extension of our work in mathematical logic) is not yet wholly operational. Our objective is to introduce students to simple proofs using the associative and commutative laws and also the definitions of natural numbers as successors of the next smallest number (for example, $2 = 1 + 1$, $3 = 2 + 1$ and $4 = 3 + 1$). Our aim is to enable the student to construct proofs of simple identities; the following would be typical instances: $5 = 2 + 3$ and $8 = (4 + 2) + 2$. We want the student to be able to tell the computer by oral command what steps to take in constructing the proof, using such expressions as REPLACE 2 BY 1 + 1 or USE THE ASSOCIATIVE LAW ON LINE 3. This program is perfectly practical with our present computer system as long as the commands are transmitted by typing a few characters on the keyboard. A major effort to substitute voice for the keyboard is planned for the coming year; our preliminary work in this direction seems promising.

But these are essentially technological problems. In summarizing some other problems that face us in the task of realizing the rich potential of computer-assisted individual instruction, I should prefer to emphasize the behavioral rather than the technological ones. The central technological problem must be mentioned, however; it has to do with reliability. Computer systems in education must work with a much higher degree of reliability than is expected in computer centers where the users are sophisticated scientists, or even in factory-control systems where the users are experienced engineers. If in the school setting young people are put at computer terminals for sustained periods and the program and machines do not perform as they should, the result is chaos. Reliability is as important in schools as it is in airplanes and space vehicles; when failure occurs, the disasters are of different kinds, but they are equally conclusive.

The primary behavioral problem involves the organization of a curriculum. For example, in what order should the ideas in elementary mathematics be presented to students? In the elementary teaching of a foreign language, to what extent should pattern drill precede expansion of vocabulary? What mixture of phonics and look-and-say is appropriate for the beginning stages of reading? These are perplexing questions. They inevitably arise in the practical context of preparing curriculum materials; unfortunately we are far from having detailed answers to any of them. Individualized instruction, whether under the supervision of a computer or a human tutor, must for some time proceed on the basis of practical judgment and rough-and-ready pedagogical intuition. The magnitude of the problem of evolving curriculum sequences is difficult to overestimate: the number of possible sequences of concepts and subject matter in elementary school mathematics alone is in excess of 10^{100}, a number larger than even generous estimates of the total number of elementary particles in the universe.

One of the few hopes for emerging from this combinatorial jungle lies in the development of an adequate body of fundamental theory about the learning and retention capacity of students. It is to be hoped that, as systematic bodies of data become available from computer systems of instruction, we shall be able to think about these problems in a more scientific fashion and thereby learn to develop a more adequate fundamental theory than we now possess.

Another problem arises from the fact that it is not yet clear how critical various kinds of responses may be. I have mentioned the problem of interpreting sentences freely presented by the student, either by the written or by the spoken word. How essential complex constructed responses to such questions may be in the process of learning most elementary subjects is not fully known. A problem at least as difficult as this one is how computer programs can be organized to take advantage of unanticipated student responses in an insightful and informative way. For the immediate future perhaps the best we can do with unanticipated responses is to record them and have them available for subsequent analysis by those responsible for improving the curriculum.

The possible types of psychological "reinforcement" also present problems. The evidence is conflicting, for instance, whether students should be immediately informed each time they make a mistake. It is not clear to what extent students should be forced to seek the right answer, and indeed whether this search should take place primarily in what is called either the discovery mode or the inductive mode, as opposed to more traditional methods wherein a rule is given and followed by examples and then by exercises or problems that exemplify the rule. Another central weakness of traditional psychological theories of reinforcement is that too much of the theory has been tested by experiments in which the information transmitted in the reinforcement procedure is essentially very simple; as a result the information content of reinforcement has not been sufficiently emphasized in theoretical discussions. A further question is whether or not different kinds of reinforcement and different reinforcement schedules should be given to children of different basic personality types. As far as I know, variables of this kind have not been built into any large-scale curriculum effort now under way in this country.

Another pressing problem involves the effective use of information about the student's past performance. In standard classroom teaching it is impossible to use such records in a sensitive way; we actually have little experience in the theory or practice of the use of such information. A gifted tutor will store in his own memory many facts about the past performance of his pupil and take advantage of these facts in his tutorial course of study, but scientific studies of how this should be done are in their infancy. Practical decisions about the amount of review work needed by the individual, the time needed for the introduction of new concepts and so forth will be mandatory in order to develop the educational computer systems of the future. Those of us who are faced with making these decisions are aware of the inadequacy of our knowledge. The power of the computer to assemble and provide data as a basis for such decisions will be perhaps the most powerful impetus to the development of education theory yet to appear. It is likely that a different breed of education research worker will be needed to feel at home with these vast masses of data. The millions of observational records that computers now process in the field of nuclear physics will be rivaled in quantity and complexity by the information generated by computers in the field of instruction.

When students are put to work on an individualized basis, the problem of keeping records of their successes and failures is enormous, particularly when those records are intended for use in making decisions about the next stage of instruction. In planning ways to process the records of several thousand students at Stanford each day, we found that one of the most difficult decisions is that of selecting the small amount of total information it is possible to record permanently. It is not at all difficult to have the data output run to 1,000 pages a day when 5,000 students use the terminals. An output of this magnitude is simply more than any human being can digest on a regular basis. The problem is to reduce the data from 1,000 pages to something like 25 or 30. As with the other problems I have mentioned, one difficulty is that we do not yet have the well-defined theoretical ideas that could provide the guidelines for making such a reduction. At present our decisions are based primarily on pedagogical intuition and the traditions of data analysis in the field of experimental psychology. Neither of these guidelines is very effective.

A body of evidence exists that attempts to show that children have different cognitive styles. For example, they may be either impulsive or reflective in their basic approach to learning. The central difficulty in research on cognitive styles, as it bears on the construction of the curriculum, is that the research is primarily at an empirical level. It is not at all clear how evidence for the existence of different cognitive styles can be used to guide the design and organization of individualized curriculum materials adapted to these different styles. Indeed, what we face is a fundamental question of educational philosophy: To what extent does society want to commit itself to accentuating differences in cognitive style by individualized techniques of teaching that cater to these differences? The introduction of computers in education raises this question in a new and pressing way. The present economics of education is such that, whatever we may think about the desirability of having a diverse curriculum for children of different cognitive styles, such diversity is not possible because of the expense. But as computers become widely used to offer instruction in the ways I have described here, it will indeed be possible to offer a highly diversified body of curriculum material. When this occurs, we shall for the first time be faced with the practical problem of deciding how much diversity we want to have. That is the challenge for which we should be prepared.

HOW TO COLLECT, INTEGRATE AND DISTRIBUTE DATA

If any one symbol can represent the rapid changes of the "sizzling sixties," it's the computer. Data processing has won not only wide acceptance as a vital function of efficient business operations, but is growing more sophisticated with greater reliance on real-time operations.

In turn, this reliance on real-time processing has placed renewed emphasis on data communications. Data must be available quickly for management to make timely, accurate decisions. And, regardless how sophisticated your data system may be, Teletype sets remain the simplest, most reliable and least costly terminal equipment for collecting, integrating and distributing data.

The integration of communications within data processing systems has helped solve many business problems by:

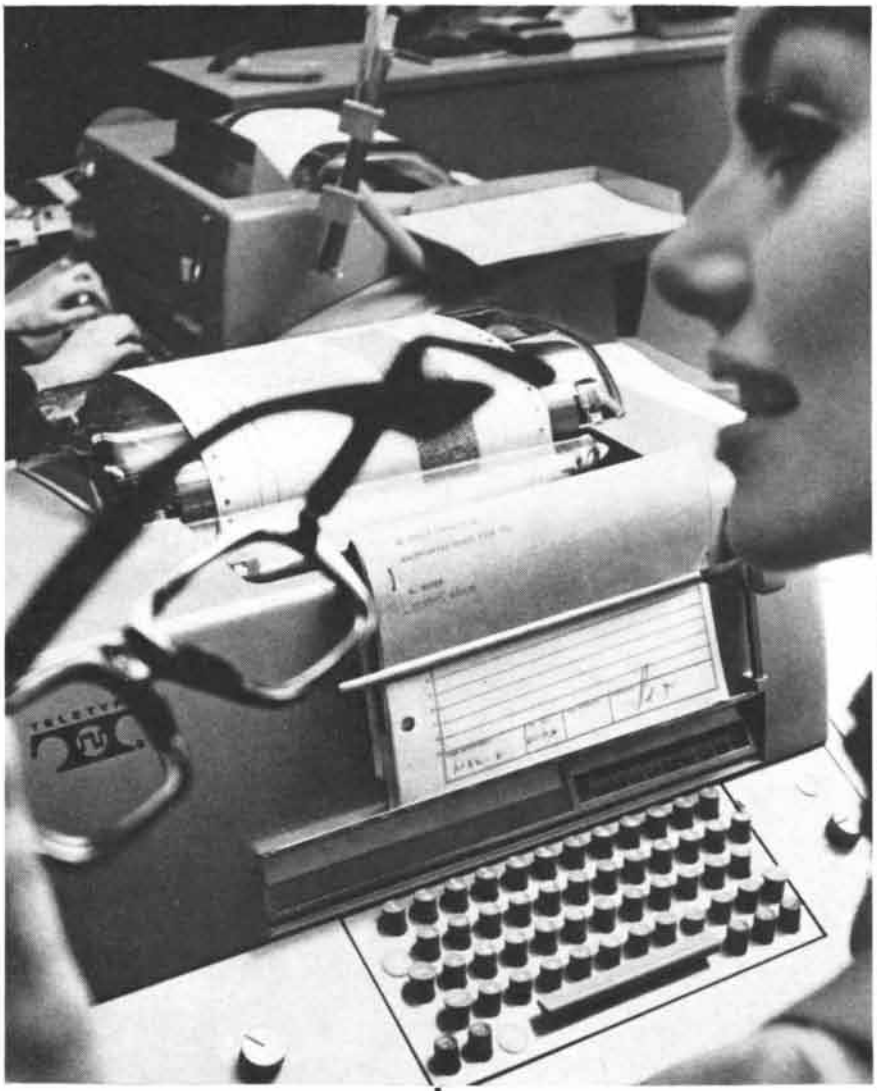
- Assuring management of adequate, timely information to make accurate decisions,
- Eliminating the costly errors caused by duplicated paperwork,
- Speeding distribution by cutting costly paperwork,
- Reducing customer complaints, and
- Enabling management to communicate quickly with remote computer centers.

Getting data in time for decisions Nothing can be as useless to you as information that arrives too late. Wrong decisions are made. Production is slowed. Deliveries are late. Customers are dissatisfied or lost. Yet, none of these situations need ever exist.

Using Teletype machines for communications within a data processing system, assures you of getting information where you need it — when you need it. You'll be able to make better informed, more timely decisions that could spell the difference between profit and loss.

This problem faced a New Jersey food processor, who had been receiving sales and inventory statistics by mail from its two branch offices. By the time these reports were processed, the information was too old to use in reaching important management decisions. The processor had Teletype ASR (automatic send-receive) sets installed at all three locations. Now, daily statistics are received in minutes and processed into up-to-date reports. This reduces inventory costs and enables the processor to close its books eight days earlier each month.

Eliminating duplicate paperwork errors How often do errors in order processing result in producing the wrong size or quantity? How often have prices been misquoted or customers lost due to incorrect shipments? These are typical problems



resulting from errors caused by duplicating data from one department to another. You can eliminate these situations with a system that speeds the handling and processing of data by including Teletype communications equipment.

Sales order information can be prepared on Teletype machines, reviewed, and transmitted directly to Teletype receiving sets in other departments. In addition to sending each department accurate information, Teletype sets can selectively "edit" this information. Thus, such data as order numbers can be sent to all departments, while cost data is directed only to accounting, billing and management departments.

This is what a metal products manufacturer did to cut order processing time 75 percent. By using Teletype ASR sets, minutes after an order comes in the data is sent to shipping and production departments—each receiving only the data it needs. A few of the resulting benefits include in-stock items shipped the same day, production orders scheduled three to seven days faster, overtime reduced, and errors greatly reduced.

Moving inventory faster Many companies are finding that profits are being eaten away by high inventory and distribution costs. They often find themselves having to justify a high inventory on the grounds it's needed to meet fluctuating customer requirements.

Yet, other companies have cut inventory costs while keeping a larger selection of stock on hand. They have learned that an effective data communications system eliminates inventory that stands idle waiting for slow-moving paperwork. By using Teletype equipment to link business machines with existing channels of communications, they are provided with instant, accurate data collection, integration, and distribution. Thus, they can handle a larger volume of business faster with more efficiency and less error.

Due to the rapid decay of critical radioactive pharmaceuticals, a national drug company had a serious inventory problem. To solve it, the firm had Teletype machines installed at all of its 26 branches to provide the necessary speed, efficiency and written verification required to plan production and delivery of these drugs. Now orders are instantly received by a Teletype set, and prepared, packaged and shipped almost immediately.

Reducing customer complaints Today, customer service is often the deciding factor in who gets the order. Yet, rapid expansion has greatly strained the capacities of many companies to properly service their customers. This is why computers and data communications have become so important in speeding the order processing, production and shipping operations. And, regardless of the distance, Teletype equipment plays an important role in the gathering and forwarding of information needed for fast service.

Many banks are relying on data communications equipment to improve the efficiency of their customer services. A midwestern bank uses a Teletype ASR set to transfer funds, to notify customers when loan payments are due, to speed transmittal of correspondence, and for many other related functions.

Solving your communications problems There are many other applications in which Teletype equipment helps improve business operations, such as using Teletype sets to link companies to a remote computer center on a time-sharing basis. You can see why Teletype equipment is made for the Bell System and others who require reliable, low cost communications.

Our brochure, "WHAT DATA COMMUNICATIONS CAN DO FOR YOU," further explains how an effective data communications system can cut your costs while building your profits. To obtain a copy, contact: Teletype Corporation, Dept. 35J, 5555 Touhy Avenue, Skokie, Illinois 60076.

TELETYPE

INFORMATION STORAGE AND RETRIEVAL

Computers and various means of storing information in highly reduced form are making libraries more efficient, but the goal of providing instant access to almost everything ever published remains distant

by Ben-Ami Lipetz

One of man's unique characteristics is his ability to communicate his thoughts and experience to his fellows. He communicates not only by means of transient sounds and gestures, as various other animals do to some extent, but also by means of durable packets of intelligible information in such forms as handwriting, printing, drawings, photographs, sound recordings and instrument traces. These durable packets of information—which accumulate by the millions, if not the billions, each year—can be collectively described as records. Records can be, and frequently are, gathered into organized collections from which they can be recovered as the need arises. The field of information storage and retrieval is thus concerned with methods of creating and managing collections of records to facilitate the recovery of pertinent records as they are needed.

Ideally the individual would like to have both access to large numbers of potentially useful records and the ability to retrieve rapidly and accurately the particular records that pertain to each of his specific needs as it arises. Some 20 years ago the emergence of electronic technology for computation and data processing, and the rapid improvement of photographic technology, inspired in people working in these fields the dream of putting huge collections of records, such as the entire Library of Congress, at the fingertips of any user anywhere, and of giving each user the means to search such a collection almost instantaneously. The transmission of records, the translation of foreign languages, the integration of newly acquired information into the collection—all would be accomplished automatically.

In spite of the extraordinary advances in computer technology, described by the authors of other articles in this issue, we are still a long way from the implementation of this dream. Why has it proved so elusive?

Exceptional progress has been made in providing high-speed access to carefully defined and limited stores of records. With progress, however, has come the realization that the ultimate goal is far more difficult to achieve than had been thought earlier. It involves not only the development of techniques for storing and manipulating records but also the improvement of our understanding and simulation of the ways in which people make associations and value judgments, together with the development of more reliable methods of predicting human information needs. The problem is largely an intellectual one, not simply one of developing faster and less expensive machinery.

The use of information storage and retrieval systems is a matter of everyday experience for literate people. The public lending library is perhaps the most widely known example. Most readers will be familiar also with specialized research libraries and technical information centers of various kinds. But information storage and retrieval is not confined to libraries; it is commonplace in everyday life. Correspondence files, accounting systems, inventory-control systems, directories—all are information storage and retrieval systems. So are collections of cooking recipes or of amateur color slides. Even the ubiquitous dictionary, as well as the index to a book or a journal, is an example of information storage and retrieval systems. All these examples are comprised of records to which one may address a variety of allowable questions (that is, questions within the intended scope of the collection) with a reasonable expectation of retrieving a selection of records in response to each question.

Many seemingly different activities can be observed in information storage and retrieval systems. Operationally, however, all such systems employ only three basic processes: the analysis of records, the derivation of new records from old ones and the physical displacement of records over a distance. Analysis is the central ingredient that determines whether and how new records should be created and whether existing records should be transferred or transmitted. In analyzing a record one compares it with something—another record, a list of significant features to be examined or information already assimilated in one's mind. Subsequent action is determined by the finding of a match or a mismatch between the record and the thing with which it is being compared. Finding or not finding a specified feature in a record implies comparison. Satisfactory comparison, however, requires the ability to recognize the important features in a record. This is not an easy task to turn over to a machine.

Provided that effective methods of analysis can be devised, an information storage and retrieval system operates as follows. Records are gathered or in-

"KWIC" INDEX, which stands for Key Word in Context, is a computer-produced concordance (*opposite page*) in which every significant word in the title of a scientific paper appears alphabetically in a list that provides all or most of the full title and the complete reference in code. The index, which contains titles from 690 leading journals, constitutes the weekly *Chemical Titles*, published by Chemical Abstracts Service.

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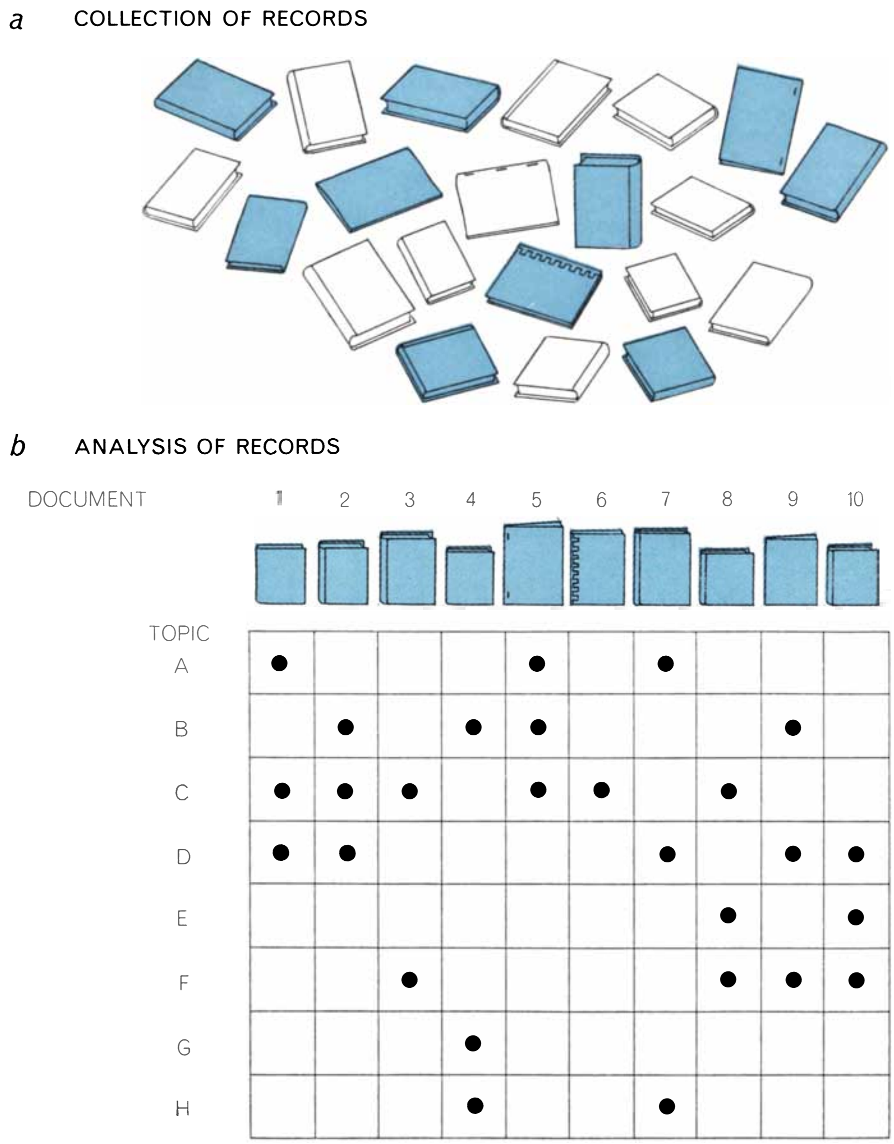
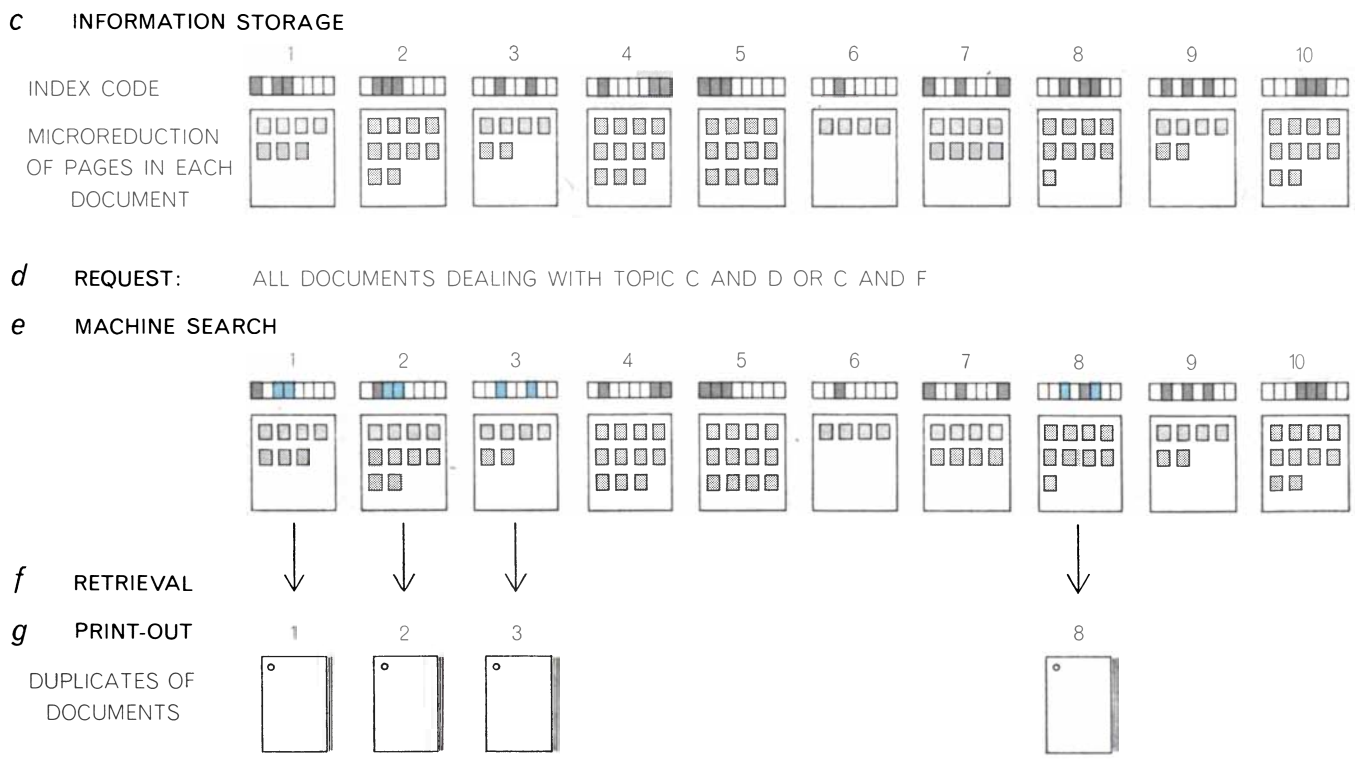
WITH AN EXTRACTIVE	DISTILLATION UNIT FOR THE MANUFACT	CHTE-A-0017-0738
HIGH VACUUM FRACTIONAL	DISTILLATION.=+OF LITHIUM METAL BY	JESO-A-0113-0201
FROM A DESTRUCTIVELY	DISTILLED TUIMASY SLACK WAX.=	ERKO-A-0018-0870
MAGNETIC RESONANCE +	DISTORTIONAL NARROWING OF NUCLEAR	PHLT-A-0019-0653
CHAIN WITH RANDOMLY	DISTRIBUTED IMPURITY SPRINGS.=	PHRV-A-0141-0710
VIBRATIONAL FREQUENCY	DISTRIBUTIONS AND THE SECOND ORDER	PHRV-A-0141-0696
AND GAMMA RAY ANGULAR	DISTRIBUTIONS FOR EVEN AND ODD	RMPH-A-0038-0143
AND ANGULAR	DISTRIBUTIONS OF THE CARBON-12(LIT	PHRV-A-0141-1007
THE+EFFECT OF INTERNAL	DISTRIBUTORS IN A PACKED COLUMN ON	JAOC-A-0042-1152
F THE EPIDAUROS LIMIRAS	DISTRICT.= COMPOSITION OF MUSTS O	CCRN-A-0030-0201
IN THE TRI-STATE	DISTRICT, MISSOURI, KANSAS, OKLAHO	ECGL-A-0060-1607
SUPPLIED FROM VARIOUS	DISTRICTS AND ISOLATION OF ISO	YKKZ-A-0085-1090
TS WITH RADIATION SICK+	DISTURBANCE IN THYMINE DECAY IN RA	BEBM-A-60-12-043
OF SOME 2,4-	DISUBSTITUTED DERIVATIVES OF 1,3-D	JSOO-A-1966-0208
ONOSUBSTITUTED AND 4,5-	DISUBSTITUTED DERIVATIVES.= + 4-M	JHTC-A-0002-0348
ROUTES TO SYMMETRICALLY	DISUBSTITUTED FERROCENES.= *	JSOO-A-1966-0251
R REARRANGEMENT TO 2,3-	DISUBSTITUTED INDOLES.= + AND THEI	JOCE-A-0031-0077
SYNTHESIS OF MONO- AND	DISUBSTITUTED THIO AMIDES.=	BSCF-A-1965-3623
S + PREPARATION OF 1,2-	DISUBSTITUTED VINYL SULFONIUM SALT	ANCE-A-0077-1140
PREPARATION OF 4,5-	DISUBSTITUTED-1,2,3-TRIAZOLES.=	JHTC-A-0002-0488
YDROCHLORIC ACID, USING	DITHIZONE IN TOLUENE.=+ AND 0.1N H	CANW-A-0010-1247
S OF OSMOTIC AND SALINE	DIURESIS AND OF ETHACRYNIC ACID.=	AJPH-A-0210-0243
E IMINES IN RELATION TO	DIURETIC ACTION.=+ CERTAIN ETHYLEN	BCPC-A-0014-1847
OF FUROSEMIDE, A NEW	DIURETIC AGENT, ON RENAL CONCENTRA	CJPP-A-0044-0129
NTO BARBITAL IN +	DIURETIC EFFECTS OF INACTIN AND PE	PSEB-A-0120-0864
IC ACTIVITY OF BONE +	DIURNAL PERIODICITY IN THE METABOL	AJPH-A-0210-0411
R VARIABLE+CONVENTIONAL	DIVISION OF DIMENSIONAL AND ANGULA	AENG-A-0019-0540
GROUPS DURING CELL	DIVISION OF SEA URCHIN EGGS.	BBAC-A-0112-0132
OF COMPLEXES BETWEEN	DNA AND ANTIBIOTICS WHICH AFFECT	BICH-A-0005-0236
UES OF HIGHER + NUCLEAR	DNA AND CYTO PLASMIC DNA FROM TISS	JCLB-A-0027-0451
ACID AND LIGHT ON RNA,	DNA AND GROWTH OF THE THREE BASAL	PYTC-A-0005-0193
FOR THE EXTRACTION OF	DNA AND PROTEIN GHOSTS FROM BACTER	BBRC-A-0022-0106
OF THE REPLICATE FORM	DNA AT VARIOUS STAGES OF INFECTION	JMOB-A-0014-0348
ERATION OF ADENINE FROM	DNA BY HYDROGEN PER OXIDE.= LIB	NATU-A-0209-0301
STUDY OF THE	DNA CONTENT IN CELL NUCLEI OF	ZOBI-A-0026-0646
FORMATION. NUCLEUS AND	DNA CONTENT IN THE ROY PARENCHYMA	NMOG-A-0011-0196
LLIUM ERECTUM.* EFFECT+	DNA CONTENT OF A CHROMOSOME OF TRI	SCIE-A-0151-0215
URCHIN + METHYLATION OF	DNA DURING DEVELOPMENT OF THE SEA	JMOB-A-0014-0603
DNA AND CYTO PLASMIC	DNA FROM TISSUES OF HIGHER PLANTS.	JCLB-A-0027-0451
AND ACTIVITY OF LAMBDA	DNA IN A SUPER INFECTED IMMUNE	JMOB-A-0014-0399
MOLECULAR WEIGHT OF THE	DNA IN THE CHROMOSOMES OF ESCHERIC	PNAS-A-0054-1636
CCHARIDE INHIBITOR OF A	DNA METHYL TRANSFERASE.= + POLY SA	PNAS-A-0054-1713
Y OF DIFFERENT PERIODIC	DNA MODELS.= + OF THE CONDUCTIVIT	JCPS-A-0044-0483
BIOLOGICAL ACTIVITY OF	DNA PREPARATIONS ISOLATED FROM	MZUK-A-27-06-073
A.* ITS RELATION TO THE	DNA REPLICATION CYCLE.=+OF BACTERI	PHCB-A-0005-0001
THYMIN+NON-CONSERVATIVE	DNA REPLICATION IN BACTERIA AFTER	PNAS-A-0054-1728
S TUMOR+DURATION OF THE	DNA SYNTHESIS PHASE IN MICE ASCITE	NATW-A-0053-0218
MATION.* INVOLVEMENT OF	DNA SYNTHESIS.=+ SUBTILIS TRANSFOR	JMOB-A-0014-0534
PRESSURE EFFECT ON	DNA TRANSITION.=	BBAC-A-0112-0179
TUDIES ON BACTERIOPHAGE	DNA. RENATURATION OF T(4) DNA.=+S	IMCH-A-0003-0041
HOT PHENOL IN PREPARING	DNA.= USE OF	PNAS-A-0054-1641
INDING OF SILVER ION BY	DNA.= + STUDIES OF THE B	BIPM-A-0004-0017
CTURE AND PROPERTIES OF	DNA.= MACRO MOLECULAR STRU	QURE-A-0019-0369
ATOMS WITH THYMINE AND	DNA.= REACTION OF HYDROGEN	PNAS-A-0054-1486
ULTRAVIOLET IRRADIATED	DNA.= ENZYMIC DEGRADATION OF	PHCB-A-0005-0119
RAT LIVER MITOCHONDRIAL	DNA.= + AND SOME PROPERTIES OF	PNAS-A-0054-1650
INE NUCLEOSIDE OF PBS 2	DNA.= + OF GLUCOSE IN THE CYTOS	BBRC-A-0022-0141
D SYNTHESIS OF CELLULAR	DNA.= + OF POLYOMA VIRUS INDUCE	PNAS-A-0054-1584
O POLYOMA AND PAPILLOMA	DNA.= BINDING OF RNA POLYMERASE T	JMOB-A-0014-0593
RENATURATION OF T(4)	DNA.=+STUDIES ON BACTERIOPHAGE DNA	IMCH-A-0003-0041
OF IN VITRO GENETIC +	DNA-RNA COMPLEX AS AN INTERMEDIATE	PNAS-A-0054-1736
OF NUCLEAR PROTEINS AND	DNA/S IN FIBROBLASTS GROWN IN	CMTR-A-0010-0103
OF THYMIDINE INTO THE	DNA/S IN MITOCHONDRIA.=	AEPP-A-0252-0258
SIDES, NUCLEOTIDES, AND	DNA/S.= + OF COPPER(II) TO NUCLEO	BICH-A-0005-0245
RIMIDINE NUCLEOTIDES IN	DNA/S.=+ OF THE DISTRIBUTION OF PY	NATU-A-0209-0296B
INITY LABELING OF ANTI-	DNP ANTIBODIES.= + OF AFF	IMCH-A-0003-0051
NES FROM OCTA SILANE TO	DODECA SILANE.= + LINEAR POLY SILA	JORC-A-0005-0120
RYLATION OF HEPTANE AND	DODECANE.= + OF CHLORO PHOSPHO	ZPKH-A-0038-2804
HAVIOR OF THE DI METHYL	DODECYL AMINE OXIDE-WATER SYSTEM.=	JAOC-A-0043-0028
OF PYRIDINE WITH	DODECYL BROMIDE IN HYDROXYLIC	KGKZ-A-0068-2093
ND + EFFECTS OF SODIUM	DODECYL SULFATE ON THE ADSORBING A	KGKZ-A-0068-2062
THYLENE BLUE AND SODIUM	DODECYL SULFATE.= + BETWEEN ME	KGKZ-A-0068-2128
MERIC SODIUM P-(THIA-N-	DODECYL)BENZENE SULFONATES.= + ISO	JAOC-A-0042-1095
HOSPHO DI ESTERASE FROM	DOG HEART.= + NUCLEOTIDE P	BICH-A-0005-0150
EFFECT OF MANGANESE ON	DOG MYOCARDIUM.= + INOTROPIC	AJPH-A-0210-0357
C UREA SYNTHESIS IN THE	DOG.= EXTRA HEPATI	BIJO-A-0097-031PB
T AMINE TOXICITY IN THE	DOG.= + OF AGGREGATION ON AMPHE	AIPT-A-0159-0196
DOLE ACETIC ACID IN THE	DOG.= + HANDLING OF 5-HYDROXY IN	PSEB-A-0120-0750
ESSING SUBSTANCE OF THE	DOG.= + RETICULO ENDOTHELIAL DEPR	AJPH-A-0210-0312
INE IN THE ANESTHETIZED	DOG.= + TO TYR AMINE BY AMPHET AM	JPET-A-0150-0375
OL AMINE RELEASE IN THE	DOG.=+ ON VENOUS RETURN AND CATECH	CJPP-A-0044-0059



serted into the collection in some orderly manner, possibly with indexing. A would-be user addresses a question to the collection. On the basis of the question a search of the collection is conducted and pertinent records are identified or retrieved. Note that the collection of records in a system has been created and organized *before* the specific questions it is to answer have been stated. In other words, the system is created in *anticipation* of needs that are not fully known. Yet the measure of adequacy of a system is its ability to satisfy its users' needs as they arise.

Is it possible to devise an information storage and retrieval system that will conveniently retrieve pertinent records in response to all possible questions? Unfortunately it is not. Any record we might choose to examine has an infinite number of real or potential attributes, any one of which could serve by its existence or absence to answer a possible question.

This can be illustrated by considering an ordinary color slide that is to be inserted in a collection of other slides. We can think at once of a number of attributes by which it could be retrieved: the date of the photograph, the location at which it was made, the names of individuals in the picture. To this we might add the name of the photographer, the type of camera, the lens,



the film, the exposure, the light or weather conditions under which the photograph was taken, the date of developing, the developing solutions used, the specific developing procedures. Each of these items could be detailed and embroidered indefinitely. If we took another tack, we could go into almost infinite detail on the content of the photograph: we could describe the relationship of the people photographed to one another or to the photographer; we could specify the presence or absence of all known or conjectured geological formations, plant or animal species, cloud formations, man-made structures and so on ad infinitum. Not only is it impossible to create an information storage and retrieval system that will respond fully to all possible questions but also it would be prohibitively expensive to try to approach such a condition. In practice all information storage and retrieval systems must adopt more modest objectives.

Designing systems to satisfy unstated needs may sound like an impossible task, yet it is being done all the time. It is accomplished by specialization. All systems, even the largest libraries, are designed with intentional or implicit limitations in scope and purpose. They do not attempt to be all things to all people. They are founded with some degree of knowledge of what kind of records are available and what general type of questions interest (or should interest) the intended users. A system can be designed for the future by extrapolating from past interests and trends; indeed, this is the only rational approach to design. As experience with a system accumulates, the requirements can often be predicted more accurately, although never with complete accuracy.

A system that is fully responsive to its users will react not only by conducting immediate searches but also by adapting its collecting and organizing activities over the long run to accommodate indicated interests and probable needs. Conversely, the users will also adapt in time to an existing system. If the system has failed to provide its users with adequate responses, and seems to them unlikely to do so in the future, unusual demands on the system may diminish as the users take their problems elsewhere. Accordingly the stability of a pattern of usage does not in itself indicate that a system is being successful in anticipating needs. Success must be related to the satisfaction and the creativeness of the *intended* users of a system, not merely of the current users. The performance of a system that is intended for highly specialized and highly restricted application is obviously far easier to gauge than the performance of a system with only vaguely defined objectives and clientele.

Two different strategies can be followed in operating an information storage and retrieval system. One is to analyze and organize the collection with great precision in the anticipation of questions. This is usually done by means of indexing. When a question arises, one would presumably have the pertinent records or their index entries already segregated from the rest of the collection, making retrieval rapid and routine. The second strategy is to avoid any unnecessary prior processing of records. When a specific question is received, a record-by-record search of the collection is made. The first strategy makes sense where needs can be anticipated precisely, where rapid retrieval is essential or where processing costs (which are proportional to the number of records processed and the detail of processing) are low compared with the alternative searching costs (which are proportional to the number of records examined in a search and the frequency of searching). The second strategy makes sense where the opposite conditions exist.

In practice virtually all systems employ a blend of the two strategies. Since the users' needs cannot be fully anticipated, some degree of record-by-record searching in response to questions is unavoidable. But some degree of prior organization of the collection according to anticipated general areas of interest will almost certainly eliminate large portions of the collection from consideration and thus make the search more efficient. The proper balance of the two strategies will vary greatly between one system and another. An example of a system at one extreme would be a military defense system, such as the SAGE air defense system or the newer missile defense system, which can be regarded as "real time" information storage and retrieval systems. In such systems rapid response or completeness of response may be all-important; therefore they tend to be elaborately organized to facilitate automatic searching of available records or data. At the other extreme a small collection of family snapshots may do very well with virtually no organization at all; on the rare and leisurely occasions when such a collection is reviewed the labor involved is neither great nor distasteful.

Most information systems will be organized to achieve the best compromise somewhere between these extremes. The compromise is shaped by economic forces that are by no means well understood. There are as yet no reliable quantitative guidelines for selecting the best mixture of service activities for a system, or for determining the precise emphasis to be given each aspect of record-processing. The intent of system planners and operators is to find a blend of processing and service activities that will give the best results for the particular operating environment, in terms of the benefits afforded to the users of the system and the costs of operating the system.

Advances in technology have had a major impact on the constituent costs of operating an information storage and retrieval system and have also widened to some extent the scope of activities that can be undertaken by a system. There is widespread and rapidly increasing use of automatic data-processing equipment,

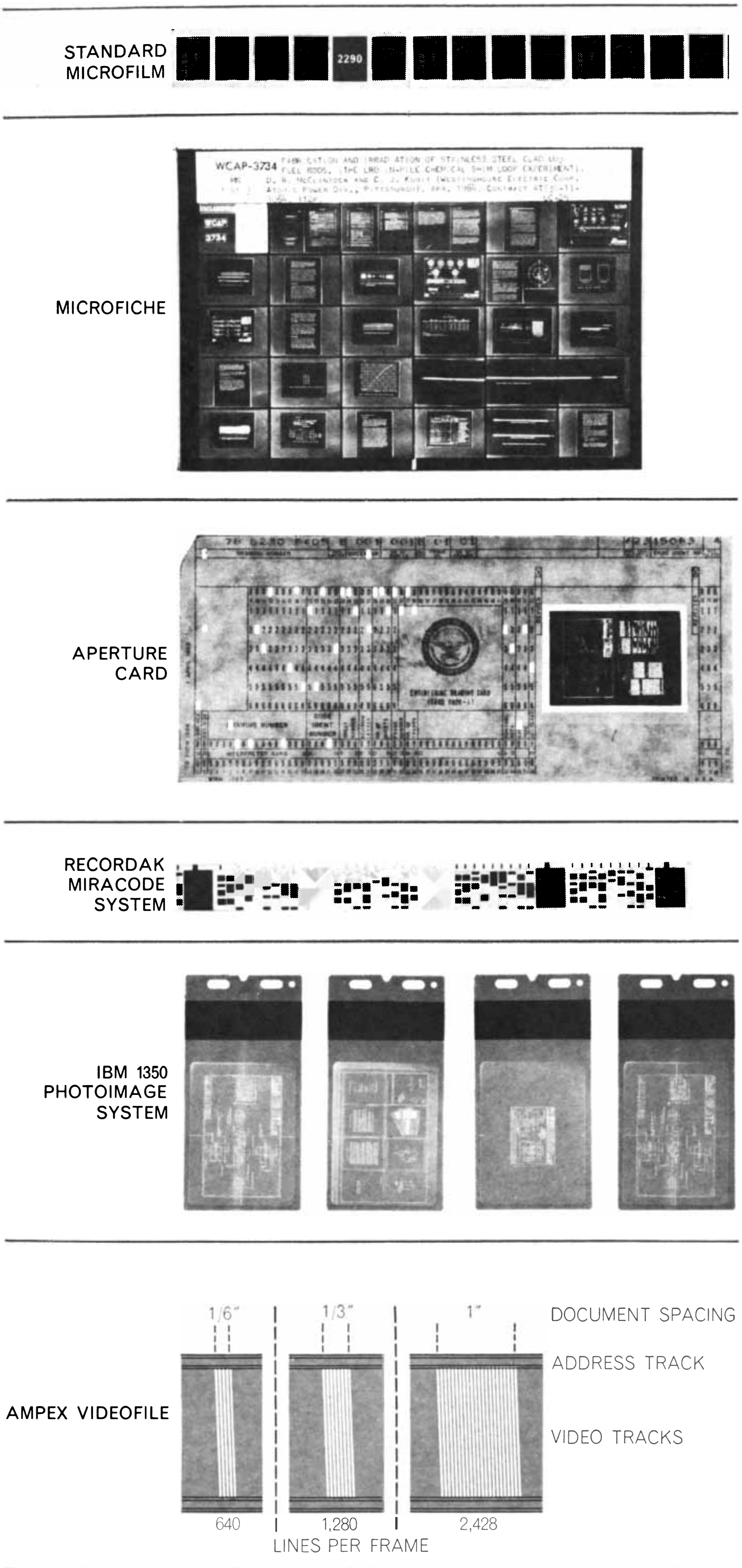
INFORMATION STORAGE AND RETRIEVAL can be partially mechanized by the technique illustrated on the opposite page. Human judgment is still required in the first two stages. The first stage (*a*) is the collection of records and the identification of those (*color*) that deal with a common area of interest, for example electrical communication. In the second stage (*b*) someone must analyze each record, or document, and decide whether or not it covers particular topics, arbitrarily limited here to eight (*A through H*). The individual pages of each document are recorded on microfilm (*c*) or other microstorage medium that provides a space for indexing in code the topics covered by each document. Here the eight spaces in the index code correspond to the letters *A* through *H*. When a request is received for information on any of the listed topics (*d*), a machine can rapidly search the index code (*e*) and retrieve the pertinent documents (*f*). The individual pages of these documents can be displayed in enlarged form for quick inspection or printed out as "hard copy" (*g*). In the request illustrated here ("All documents dealing with topics *C* and *D* or *C* and *F*") *C* might stand for "microwave relays," *D* for "coaxial cables" and *F* for "wave guides." One can imagine that the request has been placed by someone who wants to read about microwave relays only if they are discussed in conjunction with coaxial cables and wave guides. One may assume that two other documents (*No. 5 and No. 6*) that mention microwave relays are not comprehensive enough to go into these alternative ways of transmitting information.

often in association with computers, to accomplish routine clerical tasks. Techniques and machines that were evolved to handle accounting and inventory control in commerce and industry are being adopted generally in the larger libraries and in many types of specialized information storage and retrieval systems.

The parallels are clear. If machines have been developed to help process purchase orders in a business, they can be applied to help process purchase orders in a library. If machines can handle customer billing in a business, they can be used to keep track of borrowing transactions in a library. If machines can be used to manage asset accounts in a business, they can be used to help keep track of the inventory of records in a collection. If machines can produce statistical summaries of business activity, they can do the same for information-handling activity.

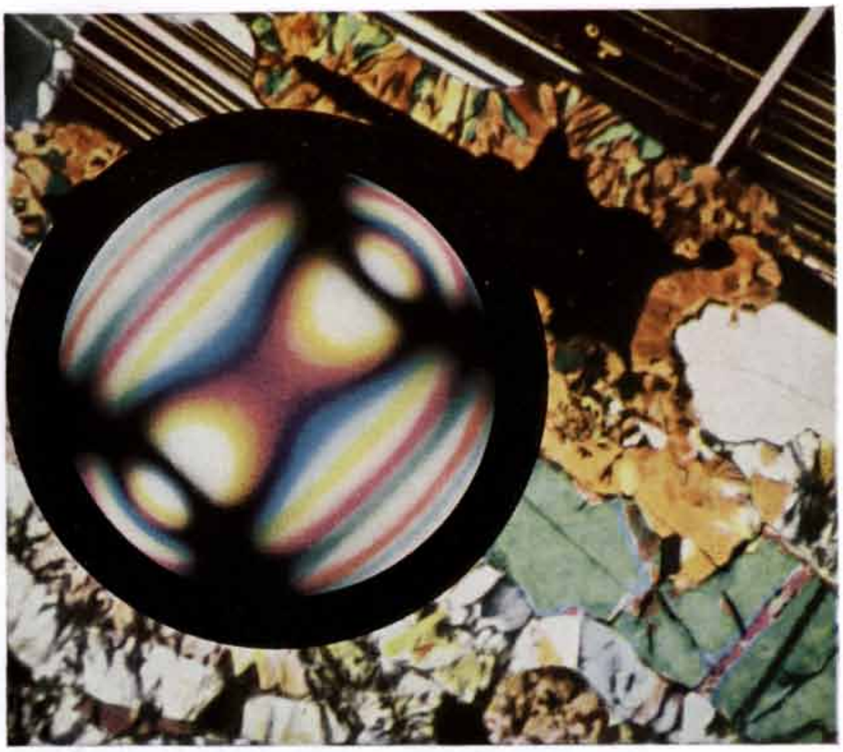
These functions all involve the manipulation of digital information. Therefore they can be handled by machines, with great savings in time and labor over manual techniques, provided that the basic records are available in a machine-readable medium such as punched cards. It takes human effort, of course, to commit these records to a machine-readable form. Since some kind of record would have to be typed or written by hand in any case, there is usually little or no added labor involved in making machine-readable records instead. Thus without even introducing any marked change in the nature of the services offered by an information storage and retrieval system, automatic data-processing techniques can often reduce the cost of routine activities and simultaneously increase the accuracy and responsiveness of the system.

A fairly typical example of how business methods have been applied to information systems is the system used



MICRORECORDING MEDIUMS take a wide variety of forms, of which representative samples are shown here about half actual size. All but standard microfilm and microfiche provide space for a machine-readable code that contains concise information about the documents recorded. In the International Business Machines system the code is recorded in magnetic form. The Videofile system of the Ampex Corporation is wholly magnetic, being an adaptation of the tape-recording system used in television. The resolution in the graphical image depends on the number of scanning lines per frame. An ordinary television image has 525 lines.

Polarization Routine Microscope POLMI A



This microscope takes flat-field Planachromats practically free from strain, together with large and flat-field eyepieces exhibiting wider fields of view than ever known before. Observation is made through an inclined eyepiece tube, incorporating an additional Bertrand lens, which may be tilted into the path of rays. An iris diaphragm accommodated also in the eyepiece tube permits individual crystals of specimens to be singled out. Adequate edge-to-edge illumination of all object fields is obtained by a triple-lens condenser. The microscope stage moves on ball bearings and can be readily arrested in any position. Polarizer and analyzer are of swing-in and rotary design. A slot in the intermediate tube Pol serves for the reception of wedge compensators and measuring compensators covering various ranges. The illuminator is built into the microscope base. This arrangement, which renders application of the Köhler illumination possible, and the coaxial arrangement of the control for coarse and fine vertical stage-adjustments contribute to convenience of operation. For examinations by incident light, a polarization incident-light condenser is available for attachment to the tube-carrier head. Supplementary and extension facilities are provided by: Four Axial FEDEROV Universal Stage, Wright Eyepiece, Photomicrographic Equipments "MF" and "ST".

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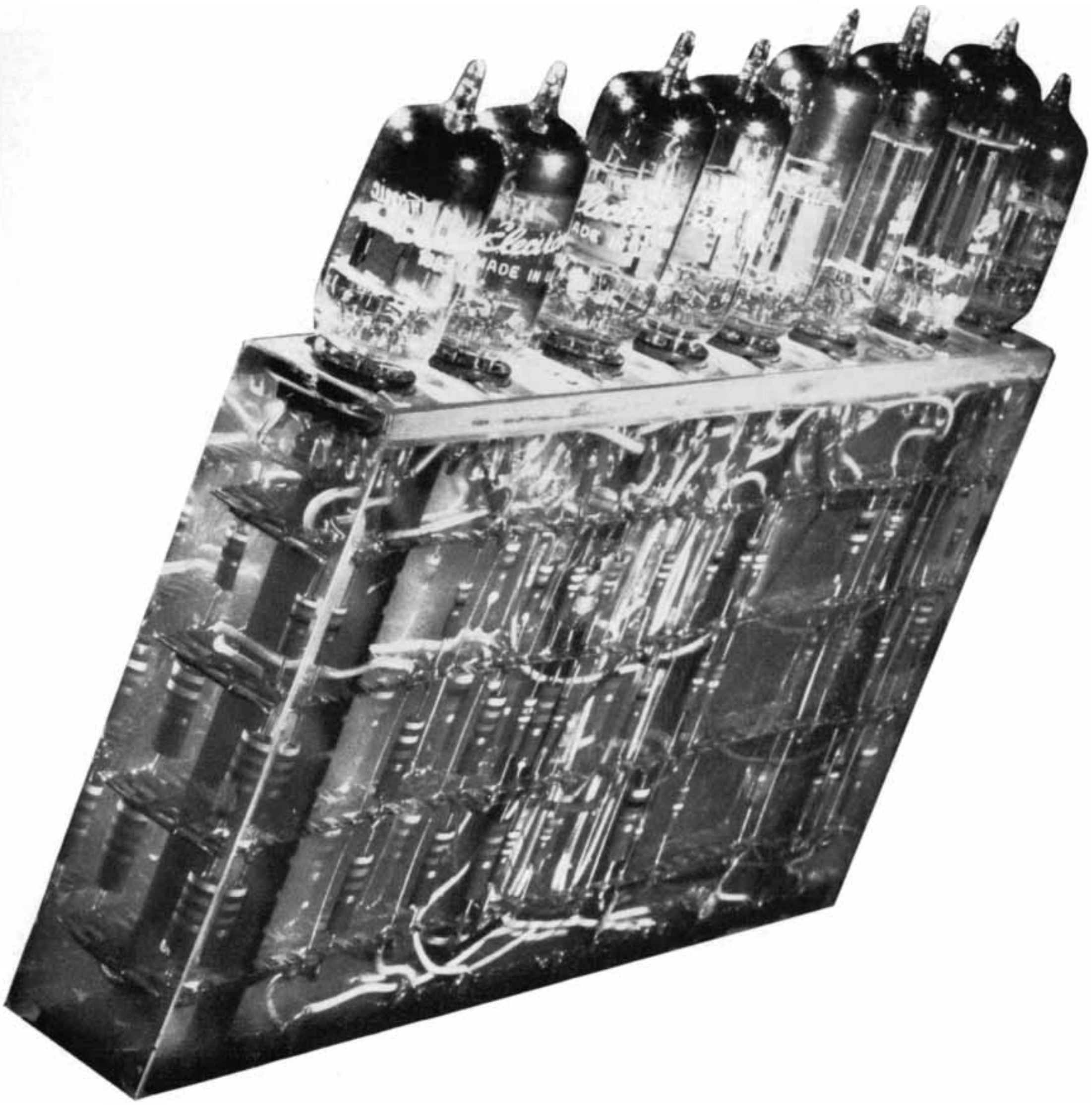


CHARACTERISTICS	MICROFICHE	APERTURE CARDS	RECORDAK MIRACODE	IBM 1350 SYSTEM	AMPEX VIDEOFILE
NORMAL STORAGE CONFIGURATION	4″ × 6″ SHEET FILM IN PAPER JACKET	35-MM. FILM FRAME IN $3\frac{1}{4}$″ × $7\frac{3}{8}$″ CARD	100-FOOT REEL 16-MM. FILM	$1\frac{3}{8}$″ × $2\frac{3}{4}$″ SHEET FILM IN PLASTIC CELL	7,200-FOOT REEL 2″ WIDE
SIZE OF STORAGE CONTAINER	30 JACKETED SHEETS PER INCH OF FILE	125 CARDS PER INCH OF FILE	4″ × 4″ × 1″	32 SHEETS IN $1\frac{1}{2}$″ × 3″ × 1″ CELL	16″ × 15″ × 3″
STORAGE CAPACITY, $8\frac{1}{2}$″ × 11″ DOCUMENTS (REDUCTION RATIO)	60 PER SHEET (20 : 1)	UP TO 8 PER CARD (24 : 1)	2,000 PER REEL (24 : 1)	256 PER CELL (24 : 1) MODULES OF 2,250 CELLS	250,000 PER REEL (1,280 LINES PER FRAME)
MAXIMUM DOCUMENTS PER CUBIC INCH	75	42	125	57	350
SEQUENTIAL SEARCH RATE	(MANUAL)	UP TO 33 CARDS PER SECOND	200 DOCUMENTS PER SECOND	(1,000 RANDOM ACCESSIONS PER HOUR)	1,050 DOCUMENTS PER SECOND

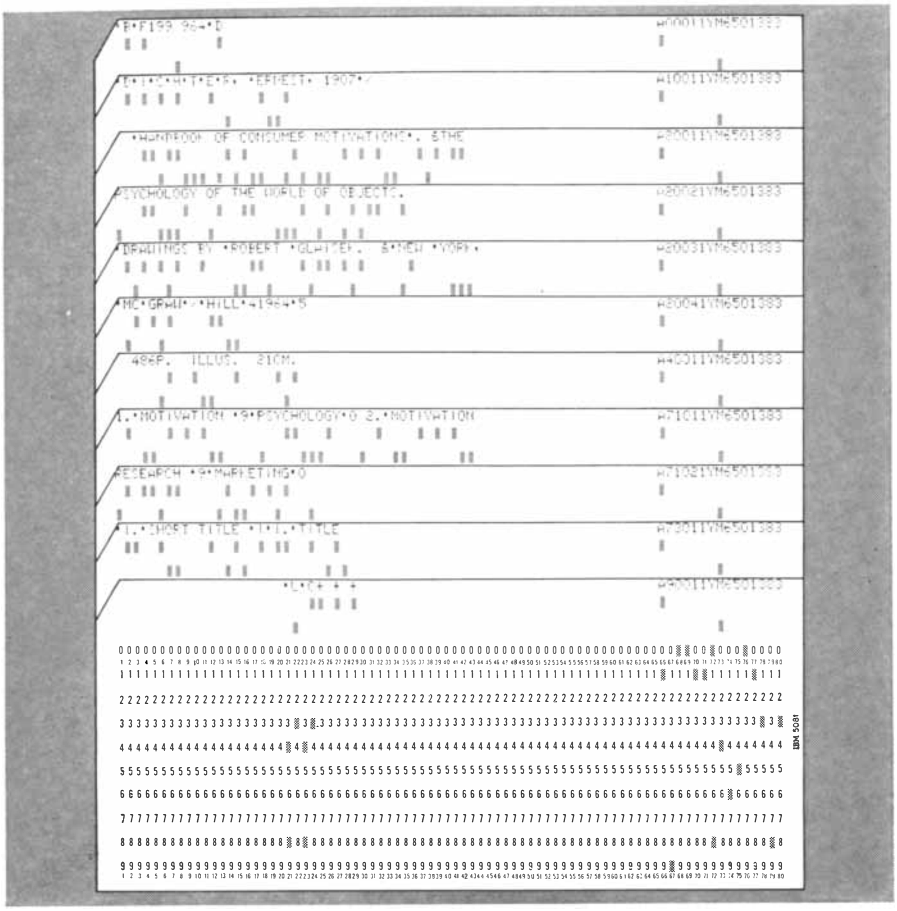
COMPARISON OF STORAGE MEDIUMS includes the storage density and other characteristics of systems illustrated on page 228. Microfiche contain no provision for machine searching. Aperture cards are usually stored in large open bins called tub files. A tub file 26 inches wide and 16 feet long will hold about 50,000 cards. If the file is well organized, a hand search can retrieve a given card at random in less than 10 seconds. To extract the same card by machine search of a small batch of cards will often take much longer. The IBM system is the only one listed that provides automatic random access to a complete store of records. A module of 2,250 plastic cells, each containing 32 film chips, can store nearly 600,000 documents. The system can be expanded to seven modules, providing storage space for more than four million documents. No IBM systems are yet in use; a one-module system sells for $188,000.

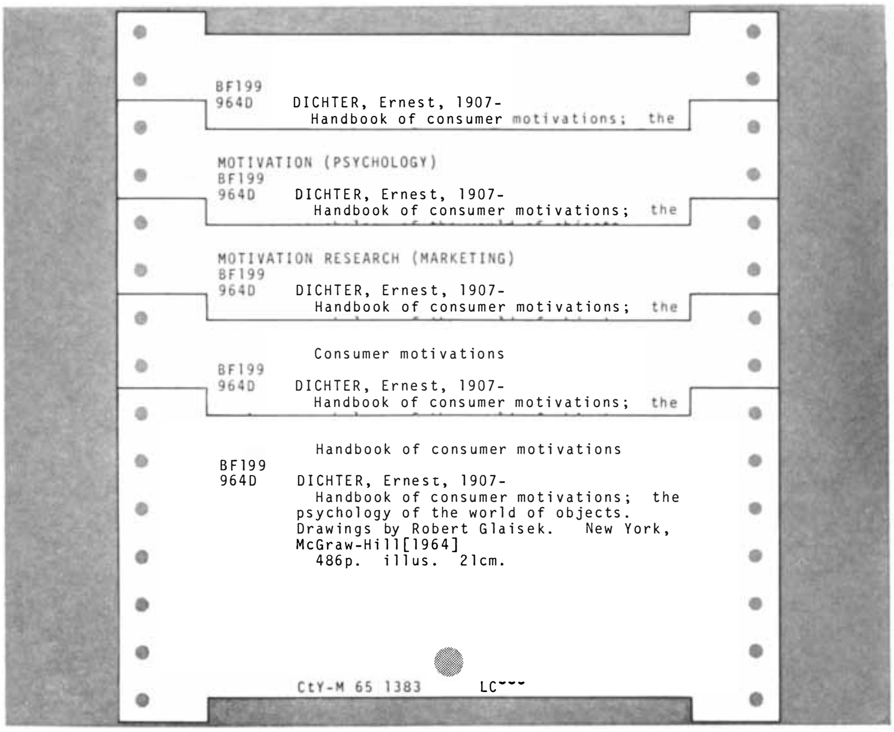
for keeping track of borrowed books at the library of the Oak Ridge National Laboratory. Each authorized borrower is supplied with a permanent machine-readable identification card, much like the credit card a department store or an oil company might supply to a customer. A similar card, bearing a different number, is kept with the book. When a book is to be borrowed, both cards are placed in a reading device that transmits the numbers to a computer together with the date. When the book is returned, the book card is used again to transmit a message to the computer indicating that the transaction has been completed. If the book is not returned on time, a notice addressed to the borrower is prepared automatically. Reports to the management on borrowing traffic, and on the precise holdings of each borrower, are also prepared routinely.

The ability of data-processing equipment and computers to generate new records by rearranging and copying from old records is extremely useful in other areas of information storage and retrieval. In the preparation of an alphabetical index to some body of literature the sorting of index entries into alphabetical order can be done by machine if the individual entries are first recorded in machine-readable form. If the final product is to be an attractive publication, the poor aesthetics of typography from early computer-driven printers (unit-spaced capital letters) is no longer a limitation. High-quality typesetting machines are now available that can be activated by the same machine-readable records computers require, or that can be coupled directly to a computer; such machines can generally set type much faster than a human operator. An advanced computer-driven typesetter is used at the National Library of Medicine in publishing *Index Medicus,* the world's largest index journal [*see illustration on page 234*].

When numerous index entries are to be derived from a single packet of information, the use of data-processing techniques can make it unnecessary to create each index entry manually. At a library, for example, a set of catalogue cards that is to be produced for a newly acquired book may consist of seven different cards; all these cards are identical except that each has a different heading inserted to indicate where it is to be filed. This heading information is obtained from statements within the text on the card. If a computer can be made to recognize each of the items in the text that is to serve as a heading, then the computer should be able to accept a single typing of the text and from it generate the full set of seven cards, each augmented with a different heading. Indeed, this is now being done at the Yale Medical Library and elsewhere [*see illustration on next page*].

The same techniques that can be applied in sorting and in augmenting rec-





CATALOGUE CARDS (*bottom*) for the Yale Medical Library are produced by computer after initial key punching of cards (*top*), which contain information from a cataloguer's work sheet. In producing the set of 11 cards the key punch operator enters only the information typed at the left. The identification data at the right has to be punched only once, then is duplicated automatically. The sequence of five catalogue cards is one of six sets printed by computer. The other five sets, which are all alike, go to Yale's main catalogue and to several other libraries. The sixth set shown here differs from the other five in that it consists of one main entry card followed by four cards with heading lines ("tracings"), which are indexed alphabetically in various parts of the main catalogue of the Yale Medical Library. The various "tracing" cards are produced automatically according to programmed instructions.

ords by computer can be used in searching a collection of machine-readable records. If the machine can recognize in a record the specific code, word or phrase, or the coincidence of two or more such key terms called for by the search question, it can seek out the pertinent records and list them, copy them, compile them or cause them to be physically retrieved or transmitted [*see illustration on page 226*]. This has been the basis for much mechanization of specialized information systems. Usually only a brief description of the primary record plus a number of index terms describing the record are committed to machine-readable form. The result of a machine search may be a series of document numbers, bibliographic descriptions of documents, abstracts or even full copies of pertinent documents, depending on the money and human effort that can be invested in creating the system. This mechanized searching ability can be found in an increasing number of systems in Federal agencies and also in industrial information systems. In the pharmaceutical and chemical industries considerable success has been achieved in developing methods to describe chemical compounds in machine-usable languages that make possible mechanized searching for particular chemical groups within complex molecules.

Although computers can scan coded records at speeds that are thousands of times faster than humans can achieve, it does not always follow that a machine search will be faster or more convenient than a manual search of a corresponding collection. For example, a file of records in alphabetical order may be stored on a magnetic tape, and a corresponding file may exist either as a card file or as a printed index. To conduct a search for a specific item on the tape by computer might take, on the average, some five minutes, since the tape must be scanned until the item is found. The same item might be found in the manual card file or book index in a few seconds because rapid access to the appropriate area is possible and irrelevant material can be skipped. Rapid-access capabilities can be given to computers too (by means of disk memories and magnetic-card memories, for example), but at present the cost of storing genuinely large collections of records in this way would usually be prohibitive. Accordingly if the questions that will be asked are known to be fairly standard and can be handled by indexing methods that are not too elaborate, the traditional manual file and printed index may still be competitive with

MEDICAL LITERATURE is indexed by the National Library of Medicine in Bethesda, Md., with the help of a Honeywell 800 computer. The sloping console at the left of center in the rear is part of GRACE (Graphic Arts Composing Equipment), a phototypesetting machine built by the Photon Corporation that produces an index to medical titles from a computer-produced magnetic tape. The results appear monthly as *Index Medicus,* which contains citations from some 2,400 medical journals. GRACE can set the 1.8 million words contained in a typical 600-page issue of *Index Medicus* in about 15 hours. A sample page from *Index Medicus* appears on page 236.

computers. The scanning speeds of computers can make them far superior, however, in responding to questions that have not been anticipated and that require record-by-record examination of a large collection.

If we turn now from the clerical activities of information storage and retrieval systems to the activities usually regarded as intellectual, such as selecting index terms, translating records and evaluating records, we find that computer techniques have made far less impact. Computers are still notoriously deficient in the ability to recognize concepts. A computer will search for a given word with great success, but it will not select a synonymous word unless it has also been given that word to search for or has been given a definition of "synonym" in machine language. This can necessitate large and expensive computer memories, excessive programming work and slowed operation where it can be done at all. Similarly, when concepts buried in multiple-word phrases must be recognized or when a foreign language must be translated, the human specialist is still quite able to compete with the computer. This is not to say that useful applications for computers are entirely lacking in these areas or that improvements cannot be expected.

One technique that achieves indexing of a sort has found considerable acceptance. This is the KWIC (Key Word in Context) index, a form of concordance generally used to index documents by the words in their titles. A computer reads all the words in all the titles and alphabetizes these words. Then it prints out these words for all the titles in alphabetical order on successive lines but keeps with these words the context of the titles and a code for locating full information. No attempt is made to associate synonyms. The user of such a list faces the chore of searching for synonyms himself. To eliminate useless printing and searching effort the computer can be instructed not to print entries for commonplace words such as "and," "the" and so on, which have no value as index terms. The journal *Chemical Titles* is such an index; it has been published for several years and serves as an express alerting service to apprise chemists of recent articles that have appeared in selected journals [*see illustration on page 225*].

Other approaches to indexing by computer have been tried and are under development. A statistical approach takes advantage of the computer's ability to count. Occurrences of different

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words in a text are counted. The terms that occur most often (other than commonplace words) are designated as index terms, on the assumption that they correlate closely with the intended topic of the record being scanned. Tests of this approach have not demonstrated the validity of the assumption. Similar statistical methods have been tried in the hope of isolating meaningful concepts by counting instances of co-occurrence of groups of words within sentences or paragraphs. A quite different approach attempts to build into computers, through programming, the capability to analyze the structure of language as humans would analyze it. This is in effect a denial that there is any inexpensive and reliable shortcut. The method is promising but requires immense human effort to develop and immense machine capability to execute.

There have been, of course, other technical developments, not involving computers, that have been of great value for information storage and retrieval systems. For example, there have been important advances in techniques for copying records and making microphotographic images. Copying devices have grown tremendously in importance and have increased in annual sales from relative insignificance 15 years ago to more than $500 million last year. Such devices can make high-quality photocopies reliably without requiring much labor. The impact on information storage and retrieval systems has been profound. Many systems now provide copies of records in preference to lending the originals; in other systems, self-service copying privileges have been accepted eagerly by patrons who would rather have a personal copy of a record than a borrowed original. Offset printing presses and other duplicating machines have also become comparatively inexpensive, reliable and convenient. It is common for information systems of any size to do far more printing now than ever of accession lists, indexes and other compilations, and to do most of it themselves.

The microfilming of records, although not a new technique (microfilming dates back more than a century), has been growing rapidly in acceptance and importance. An almost bewildering number of new techniques and devices for recording, duplicating, reading and manipulating microimages have been developed within the past decade. Although the traditional microfilm on reels is by no means obsolete, there has been increasing use of microfilm in the form of transparent film cards, called microfiche, which contain several rows of images (corresponding to the length of a typical research report) and which can be handled and interfiled easily. Also important has been the use of "aperture cards," which are standard punched cards for data-processing machines in which have been embedded one or more microfilm frames. Aperture cards are key-punched with index codes describing the record they carry in microfilm; when the aperture card is selected in a search, the desired record is immediately available. Aperture cards are particularly attractive as a means of storing, retrieving and duplicating engineering drawings. They have been used on a large scale in the nation's missile and space programs.

The saving of storage space is an obvious objective of the use of microfilm, but it is one that should be approached with caution. Extremely high reductions are possible, but they are rarely economical because of the penalties in higher filming expense, higher projecting expense and the difficulty of handling tiny images. A recently adopted Federal standard for microfiche reflects the view that a reduction ratio of about 1 : 20 is the most economical with present technology. A record reduced by this factor takes up one four-hundredth of its original area.

Probably even more important than space saving to many users at present is the fact that records on microfilm can be duplicated more cheaply than the full-sized originals. Microfiche, which

NYSTAGMUS

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S-2850

Part 2 of the January issue contains a categorized list of subject headings, including cross references. Their location in the categorized list is indicated by the letter-number designations (A1, B1, etc.), following each subject heading.

PHOTOCOMPOSED PAGE from *Index Medicus* shows the quality of the typography attainable with GRACE (*see illustration on page 234*). *Index Medicus* first appeared in 1879.

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are distributed in quantity by Federal research organizations such as the Atomic Energy Commission and the National Aeronautics and Space Administration, cost only a few cents each to duplicate. To print and distribute full-size copies of the original reports could easily raise the unit cost to a dollar or more. The saving in weight that results from microfilming is also important wherever much transportation of records is required.

Just as computers can be developed to select and retrieve records that exist in the form of punched cards or as records stored in their magnetic memories, a variety of computer-like devices have been developed to select and retrieve records that exist in mediums other than punched paper or magnetic memory. Fully automatic systems have been developed for detecting index codes of various types (optical film reels, film cards, magnetic cards and paper cards) and for retrieving or displaying records on demand. The magnetic-tape-recording technique developed for recording television programs, called videotape, has also been adapted for storage and high-speed searching of suitably indexed graphical records [*see illustration on page 228*].

Progress in communication has had far-reaching effects on information storage and retrieval. The telephone, which we now take for granted, made it possible for people to get much quicker service from libraries where telephone requests were accepted because the need to visit the collection was eliminated. Until now the telephone request has had to go through a human intermediary at the library before a search could be initiated, and the oral report of the search has had to be brief. The human intermediary can for many purposes now be eliminated in two different ways.

First, records can be transmitted rapidly and with increasing economy by automatic devices. Records that are already in machine-readable form can be transmitted easily over wires and microwave channels to printing devices, recording devices or computers. Records not in machine-readable form can be scanned by optical-electric devices and then transmitted, to be reconstituted at the receiving end by facsimile printers or television displays. Second, the capability of controlling the transmitting process, or even interacting with it, can be given to the human or the machine at the receiving end. Thus the individual can make use of a computer or operate scanning equipment from a remote location. With such developments the geographic boundaries of traditional information storage and retrieval systems are beginning to evaporate. In their place are beginning to emerge vast networks of compatible communication devices linking users with many specialized and overlapping collections.

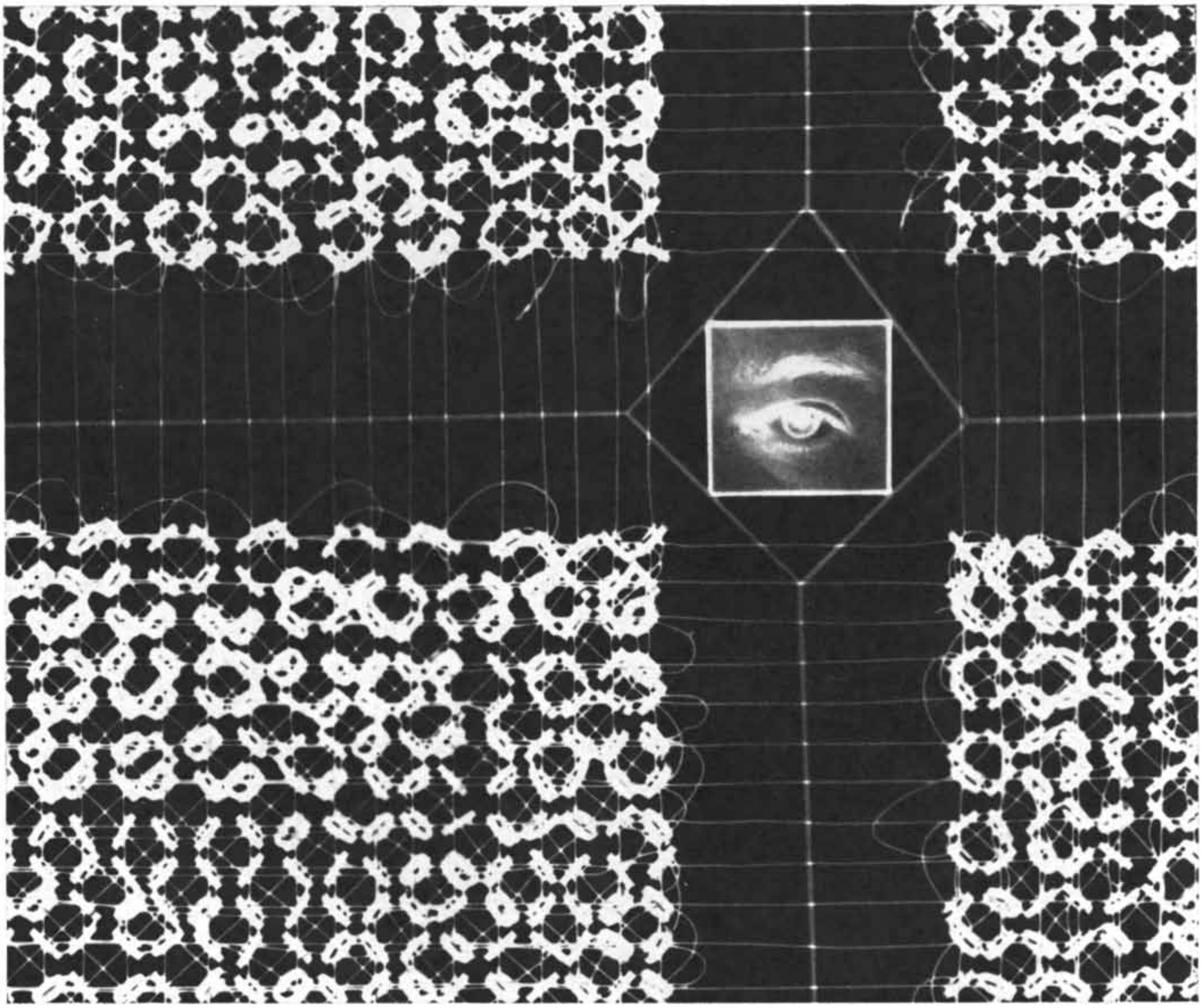
Data-transmission costs are still sufficiently high, however, to keep the dissolution of traditional systems from becoming a runaway revolutionary process. And the competition of alternative means of satisfying the users' needs for information should not be ignored. As in the case of manual systems the compromise persists in automatic systems between the processes of reacting to immediate needs and of acting in anticipation of probable needs. Direct-access, on-line communication between the user and a computer memory is in the former category. In the latter are such things as specialized directories, indexes and alerting services (usually in the form of printed matter), which can be made available to potential users through more traditional channels of communication such as the mails and can often forestall the need for direct and expensive searching of machine memories. For example, many libraries that have been converting their catalogue records to machine-readable form in order to make it possible to search

them to answer user requests are finding it desirable to publish these records in books (using the computer to control typesetting) and to distribute the book catalogues to their patrons. Numerous questions regarding holdings in the collection can then be answered by the user at his desk in seconds, without even the need for a telephone call, much less a computer search. Of course the cost of publishing book catalogues can be an argument against this policy where collections are growing so rapidly that catalogues must be revised frequently. There is no "best" solution except in a specific situation.

Another indexing procedure of growing significance is the publishing of records in machine-readable form. For example, the National Library of Medicine is now publishing monthly editions of magnetic tapes that contain the records of new acquisitions listed in *Index Medicus*. These tapes are mailed to a number of distant medical libraries that have access to compatible computer facilities. Special searches can then be made locally without any need for direct communication between the local user and the computer at the National Library of Medicine.

A major limitation in the use of machines for information storage and retrieval is their limited capacity for reading conventional printed text. Automatic print readers are not yet developed to the stage where they can read enough symbols with sufficient reliability at a sufficiently low cost to make them competitive with human transcription, except in special situations. Print readers can be used successfully in some applications where the nature and quality of the typography of the records to be read is under strict control, or where only a few symbols are to be recognized (such as the digits 0 through 9 in postal "ZIP" codes). To improve accuracy or increase symbol capacity or relax controls on input typography introduces decision-making problems that cannot be resolved without greatly complicating the equipment design.

Even when machine-readable records are somehow made available, however, the types of analysis that can be performed automatically are so far quite limited. Individual symbols can be made recognizable by storing a dictionary of symbol codes within the machine to compare with codes in the record being analyzed. Words can be recognized with fair success by giving the machine the capacity for determining boundaries



such as spaces and hyphens. Small numbers of words supplied in search questions can be stored and used as templates in scanning text. To give a machine the capacity for recognizing syllables so that it can hyphenate words when preparing columns of printed text is a major design problem. Instructing a machine to distinguish, say, a person's name from a geographic place name with good reliability is similarly difficult because of the need to bring large amounts of external knowledge to bear on the determination. And the problem of programming a machine to recognize synonymous words and phrases has scarcely been tackled. Different words and phrases are frequently synonymous only to a degree, depending on the context of the records in which they appear. Often words will have alternative —even opposite—meanings, depending on context. We are far from endowing machines with the capacity of the human intellect to associate ideas and to recognize underlying similarities in things expressed in different ways.

The difficulty of handling analytical problems has so far limited the use of mechanical techniques in information storage and retrieval work to applications that never required much analytical judgment on the part of the humans who formerly did the work. Savings in clerical activities have been great, and performance has been accelerated in such applications. But the human indexer, translator, evaluator and abstractor are still very much needed—more than ever in view of the increasing rate of production of new records. There is great need for machines to take over significant portions of the intellectual work. Faster, larger, cheaper computers are not the complete answer, although they will certainly be necessary. The major contribution will probably come from enlarged understanding of how human evaluations are made and from increased effort to design improved programs of instruction that will endow machines with analytical abilities simulating human abilities. In a real sense the problem is one of learning how to educate machines efficiently. In humans the education process takes decades and requires the accumulation of vast amounts of experience, all of which is imperfectly but quite effectively stored. There is no reason to expect that advances in computers and programs will soon yield systems with the equivalent of a college education, but the trend will be increasingly in that direction.


Medicine Men, Ontario Style

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Let's put to rest, once and for all, any notion that Ontario, Canada, is a haven for hand-me-down ideas. Ontario's researchers make news the world over. One of our surgeons, at the Hospital for Sick Children, (left) has developed an operating technique which corrects the "blue baby" condition known as transposition of the great vessels of the heart. It has been taken up and widely performed by the world's leading surgeons.
Even your space program gets a boost from our research. The space suit worn by your astronauts was pioneered in Ontario. Other Ontario firsts range from the paint roller to the electron microscope. In short, Ontario offers an encouraging climate for research and development. Canadian Government aids include: tax deductions on 100% of current *and* capital expenditures, bonus incentives, and shared cost programs for selected projects. At Sheridan Park (see story below) the Ontario Government makes available low-cost land in a research community. Assistance such as this helps researchers in Ontario put time to good use. In fact, the idea of Standard time was developed by an Ontario researcher—in 1878.

Water as cold as 29.5°F (the lowest seawater temperature possible) can now be explored in this self-contained diving suit—the first one ever made for extended use in cold water. The suit was designed and built by Ontario's Hydrospace Limited, and is slated for trials by the U.S. Navy. (Your armed forces frequently tap Ontario's research sources for new ideas and developments)

Even animals prosper through Ontario's research. The pig shown above is one of a hybrid strain developed at our Connaught Laboratories (workshop of the discoverers of insulin). Compared with average breeds, these pigs yield larger litters, require less feed, and have a much lower rate of mortality. Already, orders have been received from as far away as Summit, New Jersey and Aberdeen, Scotland.

Gasoline, golf balls, and dozens of other products are now being studied and improved at Sheridan Park, Ontario's new 350-acre research community. Aptly nicknamed "Science City," Sheridan Park houses the research facilities of a number of major industries including the engineering laboratory and design offices of Atomic Energy of Canada, Limited. By 1970 some 25 industries will be engaged in research in buildings worth 100 million dollars. The land is ideally located within a short drive of 9 Ontario universities, and is being sold at cost by the Ontario Government. Included in the plans: a scientists' club, communications centre, and international conference room to facilitate close working ties among the centre's expected 6,000 researchers. For detailed information, call, write or wire the address below.

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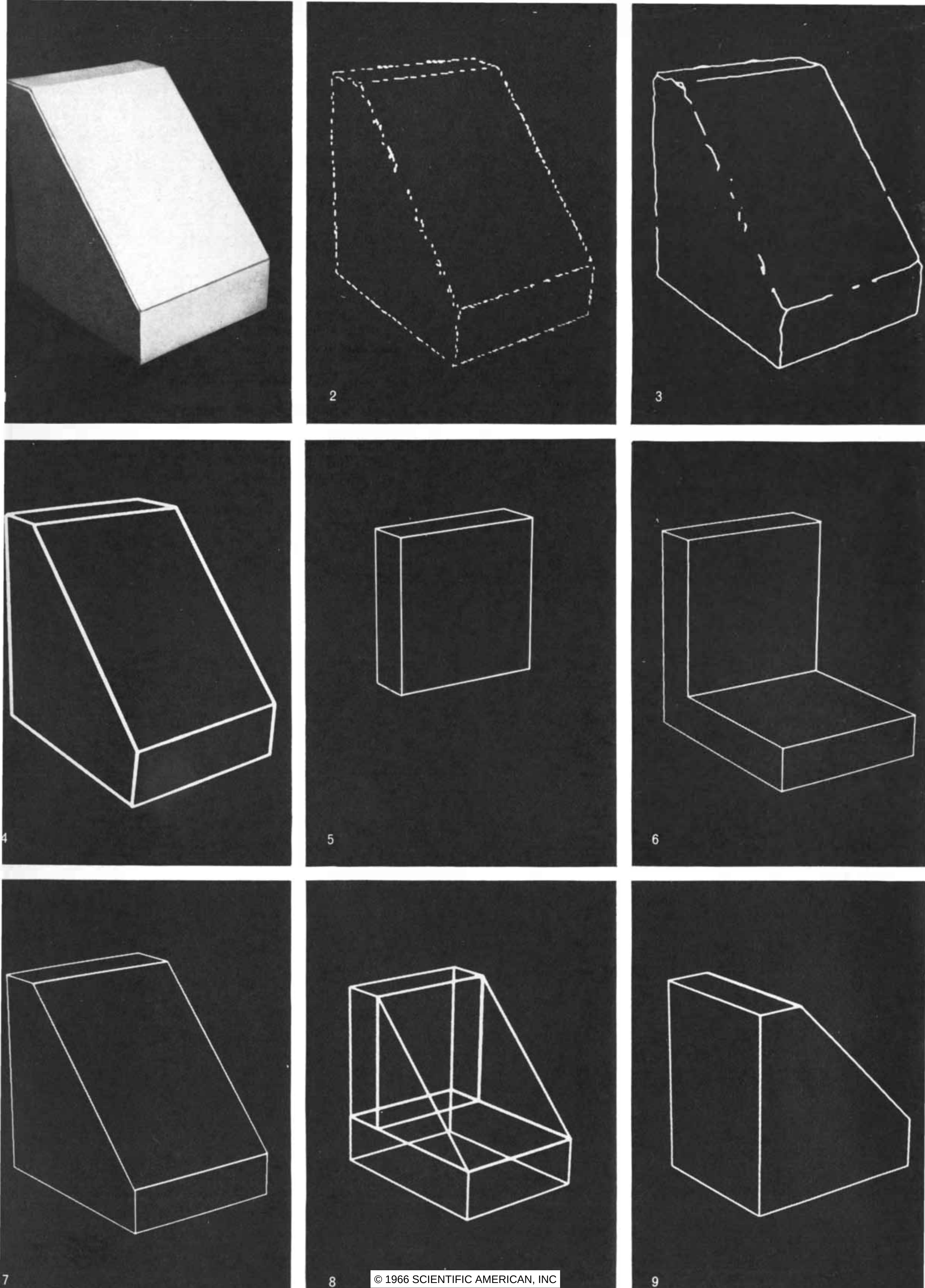
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ARTIFICIAL INTELLIGENCE

Can a machine be made to exhibit intelligence? An affirmative answer is indicated by programs that enable a computer to do such things as set up goals, make plans, consider hypotheses and recognize analogies

by Marvin L. Minsky

At first the idea of an intelligent machine seems implausible. Can a computer really be intelligent? In this article I shall describe some programs that enable a computer to behave in ways that probably everyone would agree seem to show intelligence.

The machine achievements discussed here are remarkable in themselves, but even more interesting and significant than what the programs do accomplish are the methods they involve. They set up goals, make plans, consider hypotheses, recognize analogies and carry out various other intellectual activities. As I shall show by example, a profound change has taken place with the discovery that descriptions of thought processes can be turned into prescriptions for the design of machines or, what is the same thing, the design of programs.

The turning point came sharply in 1943 with the publication of three theoretical papers on what is now called cybernetics. Norbert Wiener, Arturo Rosenblueth and Julian H. Bigelow of the Massachusetts Institute of Technology suggested ways to build goals and purposes into machines; Warren S. McCulloch of the University of Illinois College of Medicine and Walter H. Pitts of M.I.T. showed how machines might use concepts of logic and abstraction, and K. J. W. Craik of the University of Cambridge proposed that machines could use models and analogies to solve problems. With these new foundations the use of psychological language for describing machines became a constructive and powerful tool. Such ideas remained in the realm of theoretical speculation, however, until the mid-1950's. By that time computers had reached a level of capacity and flexibility to permit the programming of processes with the required complexity.

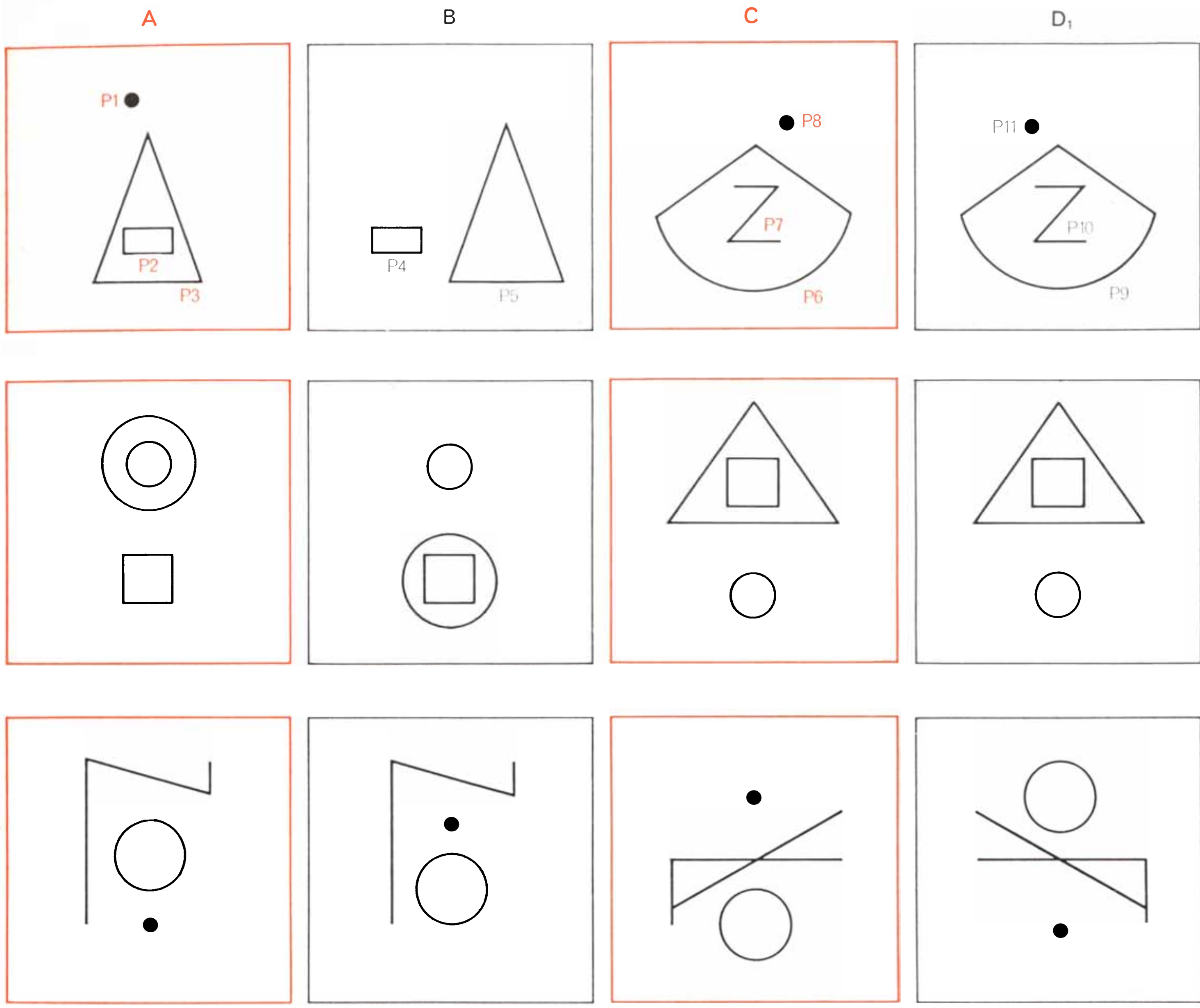
In the summer of 1956 a group of investigators met at Dartmouth College to discuss the possibility of constructing genuinely intelligent machines. Among others, the group included Arthur L. Samuel of the International Business Machines Corporation, who had already written a program that played a good game of checkers and incorporated several techniques to improve its own play. Allen Newell, Clifford Shaw and Herbert A. Simon of the Rand Corporation had constructed a theorem-proving program and were well along in work on a "General Problem Solver," a program that administers a hierarchy of goal-seeking subprograms.

John McCarthy was working on a system to do "commonsense reasoning" and I was working on plans for a program to prove theorems in plane geometry. (I was hoping eventually to have the computer use analogical reasoning on diagrams.) After the conference the workers continued in a number of independent investigations. Newell and Simon built up a research group at the Carnegie Institute of Technology with the goal of developing models of human behavior. McCarthy and I built up a group at M.I.T. to make machines intelligent without particular concern with human behavior. (McCarthy is now at Stanford University.) Although the approaches of the various groups were different, it is significant that their studies have resulted in closely parallel results.

Work in this field of intelligent machines and the number of investigators increased rapidly; by 1963 the bibliography of relevant publications had grown to some 900 papers and books. I shall try to give the reader an impression of the state of the field by presenting some examples of what has been happening recently.

The general approach to creating a program that can solve difficult problems will first be illustrated by considering the game of checkers. This game exemplifies the fact that many problems can in principle be solved by trying all possibilities—in this case exploring all possible moves, all the opponent's possible replies, all the player's possible replies to the opponent's replies and so on. If this could be done, the player could see which move has the best chance of winning. In practice, however, this approach is out of the question, even for a computer; the tracking down of every possible line of play would involve some 10^{40} different board positions. (A similar analysis for the game of chess would call for some 10^{120} positions.) Most interesting problems present far too many possibilities for complete trial-and-error analysis. Hence one must discover rules that will

ABSTRACT REASONING is required to complete a figure on the basis of partial information. A program developed by Lawrence G. Roberts in a doctoral thesis at the Massachusetts Institute of Technology allows a computer to interpret a two-dimensional image and reconstruct the three-dimensional object. As shown on the opposite page, the computer scans a photograph of the object (*1*), displays its local features (*2*) and combines line segments (*3*) to prepare a complete line drawing (*4*). It accounts for the drawing as a compound of three-dimensional shapes (*5–7*) and draws in all the interior lines (*8*). Then it can display the structure from any point of view on request, suppressing lines that would be hidden (*9*).



ANALOGICAL REASONING is exhibited in a program developed by Thomas Evans in an M.I.T. doctoral thesis for answering a class of problems frequently included in intelligence tests: "*A* is to *B* as *C* is to (D_1, D_2, D_3, D_4 or D_5?)." Three such problems are illustrated

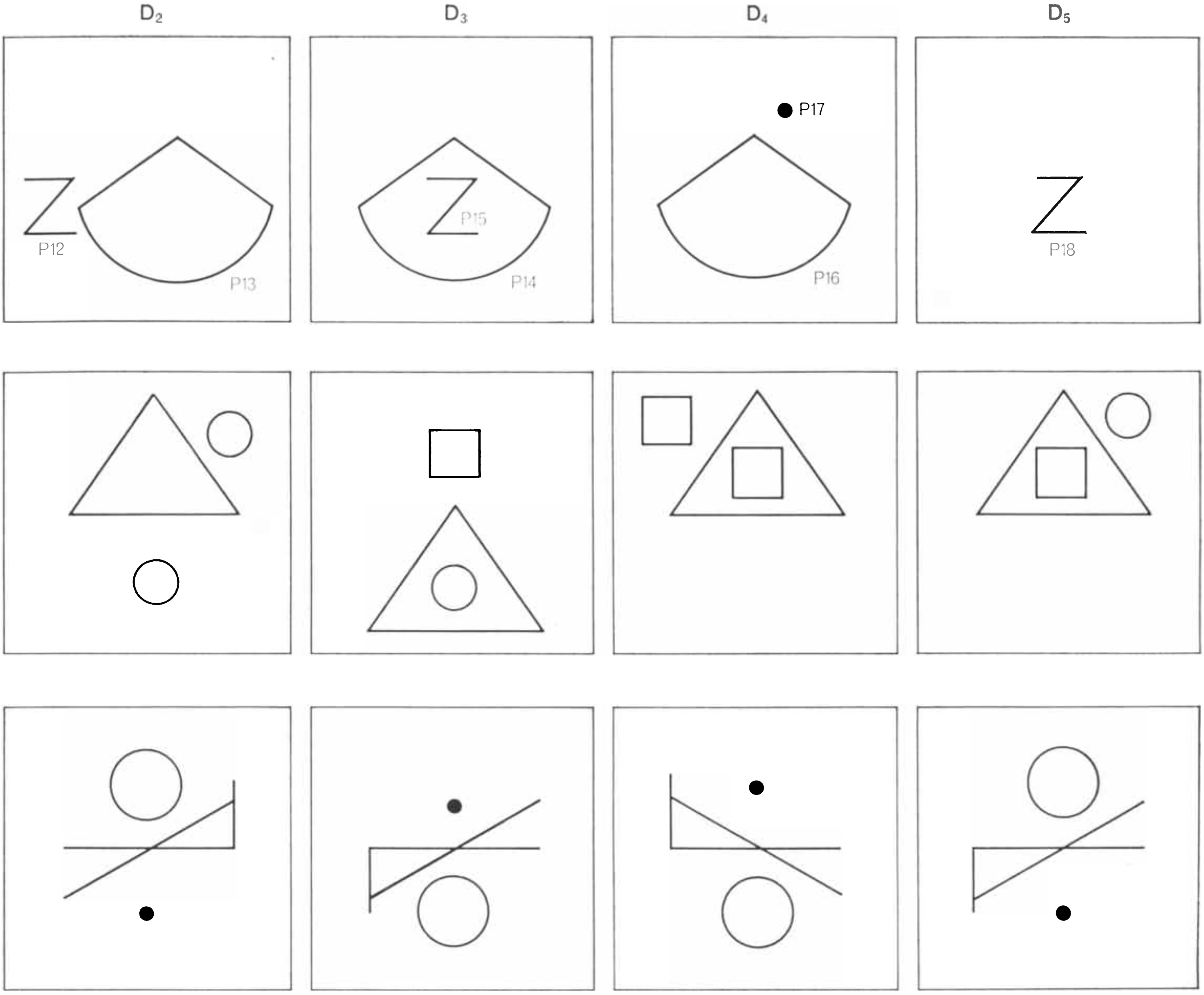
try the most likely routes to a solution as early as possible.

Samuel's checker-playing program explores thousands of board positions but not millions. Instead of tracking down every possible line of play the program uses a partial analysis (a "static evaluation") of a relatively small number of carefully selected features of a board position—how many men there are on each side, how advanced they are and certain other simple relations. This incomplete analysis is not in itself adequate for choosing the best move for a player in a current position. By combining the partial analysis with a limited search for some of the consequences of the possible moves from the current position, however, the program selects its move as if on the basis of a much deeper analysis. The program contains a collection of rules for deciding when to continue the search and when to stop. When it stops, it assesses the merits of the "terminal" position in terms of the static evaluation. If the computer finds by this search that a given move leads to an advantage for the player in all the likely positions that may occur a few moves later, whatever the opponent does, it can select this move with confidence.

What is interesting and significant about such a program is not simply that it can use trial and error to solve problems. What makes for intelligent behavior is the collection of methods and techniques that select what is to be tried next, that size up the situation and choose a plausible (if not always good) move and use information gained in previous attempts to steer subsequent analysis in better directions. To be sure, the programs described below do use search, but in the examples we present the solutions were found among the first few attempts rather than after millions of attempts.

A program that makes such judgments about what is best to try next is termed heuristic. Our examples of heuristic programs demonstrate some capabilities similar in principle to those of the checkers program, and others that may be even more clearly recognized as ways of "thinking."

In developing a heuristic program one usually begins by programming some methods and techniques that can solve comparatively uncomplicated



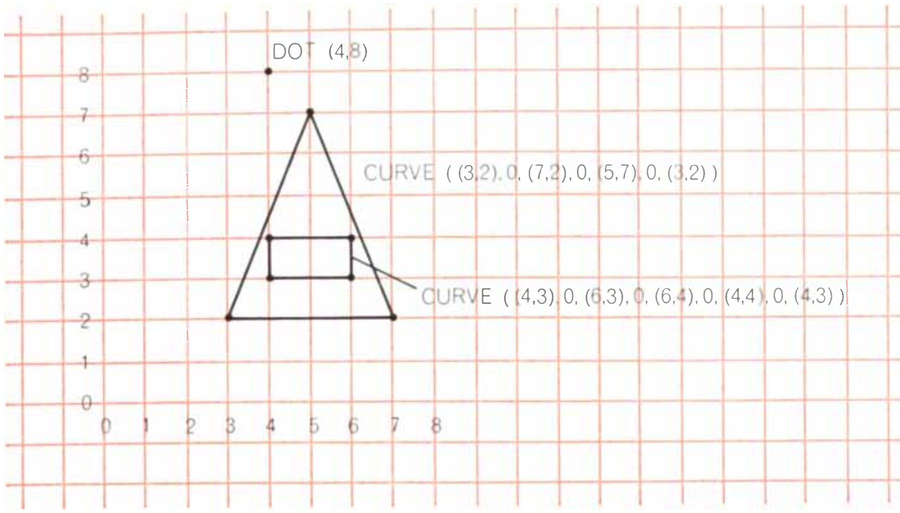
here. A computer selected the "best" answer to the top example and the middle one but missed on the bottom one because the program is weak in assessing relations among more than two objects. A typical solution is demonstrated in the illustrations that follow.

problems. To solve harder problems one might work directly to improve these basic methods, but it is much more profitable to try to extend the problem solver's general ability to bring a harder problem within reach by breaking it down into subproblems. The machine is provided with a program for a three-step process: (1) break down the problems into subproblems, keeping a record of the relations between these parts as part of the total problem, (2) solve the subproblems and (3) combine the results to form a solution to the problem as a whole. If a subproblem is still too hard, apply the procedure again. It has been found that the key to success in such a procedure often lies in finding a form of description for the problem situation (a descriptive "language") that makes it easy to break the problem down in a useful way.

Our next example of a heuristic program illustrates how descriptive languages can be used to enable a computer to employ analogical reasoning. The program was developed by Thomas Evans, a graduate student at M.I.T., as the basis for his doctoral thesis, and is the best example so far both of the use of descriptions and of how to handle analogies in a computer program.

The problem selected was the recognition of analogies between geometric figures. It was taken from a well-known test widely used for college-admission examinations because its level of difficulty is considered to require considerable intelligence. The general format is familiar: Given two figures bearing a certain relation to each other, find a similar relation between a third figure and one of five choices offered. The problem is usually written: "A is to B as C is to (D_1, D_2, D_3, D_4 or D_5?)." The particularly attractive feature of this kind of problem as a test of machine intelligence is that it has no uniquely "correct" answer. Indeed, performance on such tests is not graded by any known rule but is judged on the basis of the selections of highly intelligent people on whom the test is tried.

Now, there is a common superstition that "a computer can solve a problem only when every step in the solution is clearly specified by the programmer." In a superficial sense the statement is true, but it is dangerously misleading if



FIRST STEP of the program describes the parts of each figure in terms of a coordinate system, as shown for *A* in the top problem on the preceding two pages. The triangle and rectangle are "curves" whose apexes are connected by lines of zero curvature, indicated by *0*.

	RELATIONS WITHIN
(INSIDE (P_2,P_3), ABOVE (P_1,P_3), ABOVE (P_1,P_2))	A
(LEFT (P_4,P_5))	B
(INSIDE (P_7,P_6), ABOVE (P_8,P_6), ABOVE (P_8,P_7))	C
(INSIDE (P_{10},P_9), ABOVE (P_{11},P_9), ABOVE (P_{11},P_{10}))	D_1
(LEFT (P_{12},P_{13}))	D_2
(INSIDE (P_{15},P_{14}))	D_3
(ABOVE (P_{17},P_{16}))	D_4
(NONE)	D_5

	SIMILARITIES BETWEEN
SIM (P_2,P_4,0°) (P_2,P_4,180°) (P_3,P_5,0°)	A AND B
SIM (P_1,P_8,0°)	A AND C
NIL	B AND C
SIM (P_6,P_9,0°) (P_7,P_{10},0°) (P_7,P_{10},180°) (P_8,P_{11},0°)	C AND D_1
SIM (P_6,P_{13},0°) (P_7,P_{12},0°) (P_7,P_{12},180°)	C AND D_2
SIM (P_6,P_{14},0°) (P_7,P_{15},0°) (P_7,P_{15},180°)	C AND D_3
SIM (P_6,P_{16},0°) (P_8,P_{17},0°)	C AND D_4
SIM (P_7,P_{18},0°) (P_7,P_{18},180°)	C AND D_5
SIM (P_1,P_{11},0°) (P_1,P_{17},0°)	A AND D_1, A AND D_4

RELATIONS AND SIMILARITIES are discovered by the program. It notes, for example, that the rectangle (P_2) is inside the triangle (P_3), the dot (P_1) above both the triangle and the rectangle, and so on. Then it lists similarities between such elements in different figures and also notes whether or not the similarity persists if an element is rotated 180 degrees.

it is taken literally. Here we understood the basic concepts Evans wrote into the program, but until the program was completed and tested we had no idea of how the machine's level of performance would compare to the test scores of human subjects.

Evans began his work on the problem of comparing geometric figures by proposing a theory of the steps or processes the human brain might use in dealing with such a situation. His theory suggested a program of four steps that can be described in psychological terms. First, in comparing the features of the figures *A* and *B* one must select from various possibilities some way in which a description of *A* can be transformed into a description of *B*. This transformation defines certain relations between *A* and *B*. (For example, in the top series of drawings in the illustration on the preceding two pages a small rectangle is inside the triangle in the figure *A* and outside the triangle in the figure *B*.) There may be several such explanations "plausible" enough to be considered. Second, one looks for items or parts in *C* that correspond to parts in *A*. There may be several such "matches" worthy of consideration. Third, in each of the five figures offering answer choices one searches for features that may relate the figure to *C* in a way similar to the way in which the corresponding features in *B* are related to those in *A*. Wherever the correspondence, if any, is not perfect, one can make it more so by "weakening" the relation, which means accepting a modified, less detailed version of the relation. Fourth and last, one can select as the best answer the figure that required the least modification of relations in order to relate it to *C* as *B* is related to *A*.

This set of hypotheses became the framework of Evans' program. (I feel sure that rules or procedures of the same general character are involved in any kind of analogical reasoning.) His next problem was to translate this rather complex sketch of mental processes into a detailed program for the computer. To do so he had to develop what is certainly one of the most complex programs ever written. The technical device that made the translation possible was the LISP ("list-processor") programming language McCarthy had developed on the basis of earlier work by Newell, Simon and Shaw. This system provides many automatic services for manipulating expressions and complicated data structures. In particular it is a most convenient method of handling descriptions consisting of lists of items. And it makes it easy to write interlocked programs that can, for example, use one another as subprograms.

The input for a specific problem in Evans' program is in the form of lists of vertices, lines and curves describing the geometric figures. A subprogram analyzes this information, identifies the separate parts of the figure and reconstructs them in terms of points on a graph and the connecting lines. The steps and processes in the solution of a problem are given in some detail in the illustrations on these two pages. Briefly, the program takes the following course: After receiving the descriptions of the figures (*A*, *B*, *C* and the five answer choices) it searches out topological and geometric relations between the parts in each picture (such as that one object is inside or to the left of or above another). It then identifies and lists similarities between pairs of pictures (*A* and *B*, *A* and *C*, *C* and D_1 and so on). The program proceeds to discover all the ways in which the parts of *A* and *B* can be matched up, and on the basis of this examination it develops a hypothesis about the relation of *A* to *B* (what was removed, added, moved or otherwise changed to transform one picture into the other). Next it considers correspondences between the parts of *A* and the parts of *C*. It goes on to look for matchings of the *A*-to-*B* kind between the parts in *C* and each of the *D* figures (the answer choices). When it finds something approaching a match that is consistent with its hypothesis of the relation between *A* and *B*, it proceeds to measure the degree of divergence of the *C*-to-*D* relation from the *A*-to-*B* relation by stripping away the details of the *A*-to-*B* transformation one by one until both relations (*A*-to-*B* and *C*-to-*D*) are essentially alike. In this way it eventually identifies the *D* figure that seems to come closest to a relation to *C* analogous to the *A* and *B* relation.

Evans' program is capable of solving problems considerably more complex or subtle than the one we have considered step by step. Among other things, in making decisions about the details of a picture it can take into account deductions from the situation as a whole [*see bottom illustration on this page*]. No one has taken the trouble to make a detailed comparison of the machine's performance with that of human subjects on the same problems, but Evans' evidence suggests that the present program can score at about the 10th-grade level, and with certain improvements of the program that have already been proposed it should do even better. Evans' work on his program had to stop when he reached the limitations of the computer machinery available to him. His program could no longer fit in one piece into the core memory of the computer, and mainly for this reason it took several minutes to run each problem in the machine. With the very large memory just installed at M.I.T.'s Project MAC the program could be run in a few seconds. The new capacity will make possible further research on more sophisticated versions of such programs.

The Evans program is of course a single-minded affair: it can deal only with problems in geometrical analogy. Although its ability in this respect compares favorably with the ability of humans, in no other respect can it pretend to approach the scope or versatility of human intelligence. Yet in its limited way it does display qualities we usually think of as requiring "intuition," "taste" or other subjective operations of the mind. With his analysis of such operations and his clarification of their components in terms precise enough to express them symbolically and make them available for use by a machine, Evans laid a foundation for the further development (with less effort) of programs employing analogical reasoning.

Moreover, it is becoming clear that analogical reasoning itself can be an important tool for expanding artificial

```
(REMOVE A1 ((ABOVE A1 A3) (ABOVE
   A1 A2) (SIM OB3 A1 (((1.0 . 0.0) .
   (N.N))))))

(MATCH A2 (((INSIDE A2 A3) (ABOVE
   A1 A2) (SIM OB2 A2 (((1.0 . 0.0) .
   (N.N))))) . ((LEFT A2 A3) (SIM
   OB2 A2 (((1.0 . 0.0) . (N.N)) ((1.0 .
   3.14) . (N.N)))) (SIMTRAN (((1.0 .
   0.0) . (N.N)) ((1.0 . 3.14) . (N.N)
   ))))))

(MATCH A3 (((INSIDE A2 A3) (ABOVE
   A1 A3) (SIM OB1 A3 (((1.0 . 0.0) .
   (N.N))))) . ((LEFT A2 A3)  (SIM
   OB1  A3  (((1.0 . 0.0) . (N.N))))
   (SIMTRAN  (((1.0 . 0.0) . (N.N)
   ))))))
```

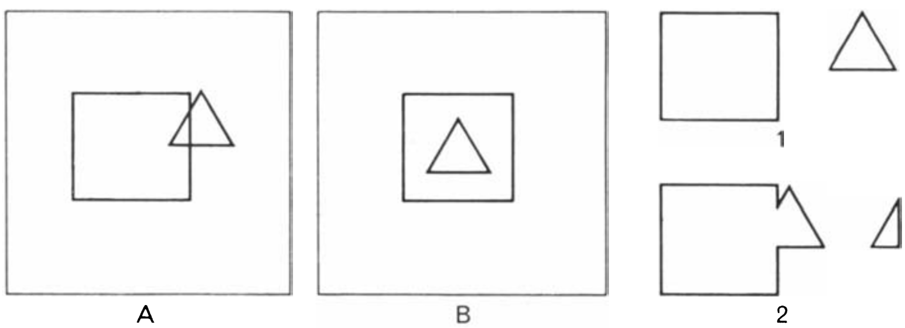
HYPOTHESIS about how *A* is related to *B* is constructed by the program, which finds ways in which parts of the two figures can be matched up. It lists each element removed, added or matched and also the properties, relations and similarities associated with the element.

```
(REMOVE A1 ((ABOVE A1 A3) (ABOVE
   A1 A2) (SIM OB3 A1 (((1.0 . 0.0) .
   (N.N))))))

(MATCH A2 (((INSIDE A2 A3) (ABOVE
   A1 A2)) . ((LEFT A2 A3) (SIMTRAN
   (((1.0 . 0.0) . (N.N)) ((1.0 . 3.14)
   (N.N))))))))

(MATCH A3 (((INSIDE A2 A3) (ABOVE
   A1 A3)) . ((LEFT A2 A3) (SIMTRAN
   (((1.0 . 0.0) . (N.N))))))))
```

PROGRAM CONCLUDES, after trying matchings between *C* and each of the five *D* figures, that D_2 is the best answer. It does so by considering *C-D* matchings that are consistent with the *A-B* hypothesis. By removing details from the *A-B* expression until it fits the *C-D* matching, the program selects the *C-D* match that is least different from the *A-B* hypothesis.



REASONING POWER of the program is illustrated in a different example by its ability to resolve the overlapping objects in *A* into a rectangle and triangle (*1*) rather than the other pieces (*2*). It makes the distinction by observing that the objects at *1* occur in figure *B* whereas the others do not. That is, program can recognize a "global" aspect of the situation.

```
(THE PROBLEM TO BE SOLVED IS)
(MARY IS TWICE AS OLD AS ANN WAS WHEN MARY WAS AS OLD AS ANN
IS NOW . IF MARY IS 24 YEARS OLD , HOW OLD IS ANN Q.)

(WITH MANDATORY SUBSTITUTIONS THE PROBLEM IS)
(MARY IS 2 TIMES AS OLD AS ANN WAS WHEN MARY WAS AS OLD AS
ANN IS NOW . IF MARY IS 24 YEARS OLD , WHAT IS ANN Q.)

(WITH WORDS TAGGED BY FUNCTION THE PROBLEM IS)
((MARY / PERSON) IS 2 (TIMES / OP 1) AS OLD AS (ANN / PERSON)
WAS WHEN (MARY / PERSON) WAS AS OLD AS (ANN / PERSON) IS NOW
(PERIOD / DLM) IF (MARY / PERSON) IS 24 YEARS OLD , (WHAT /
QWORD) IS (ANN / PERSON) (QMARK / DLM))


(THE SIMPLE SENTENCES ARE)

((MARY / PERSON) S AGE IS 2 (TIMES / OP 1) (ANN / PERSON) S
AGE G02521 YEARS AGO (PERIOD / DLM))

(G02521 YEARS AGO (MARY / PERSON) S AGE IS (ANN / PERSON) S
AGE NOW (PERIOD / DLM))

((MARY / PERSON) S AGE IS 24 (PERIOD / DLM))

((WHAT / QWORD) IS (ANN / PERSON) S AGE (QMARK / DLM))


(THE EQUATIONS TO BE SOLVED ARE)

(EQUAL G02522 ((ANN / PERSON) S AGE))

(EQUAL ((MARY / PERSON) S AGE) 24)

(EQUAL (PLUS ((MARY / PERSON) S AGE) (MINUS (G02521))) ((ANN
/ PERSON) S AGE))

(EQUAL ((MARY / PERSON) S AGE) (TIMES 2 (PLUS ((ANN / PERSON)
S AGE) (MINUS (G02521)))))


(ANN S AGE IS  18)
```

"STUDENT," an English-reading program created by Daniel Bobrow, solves algebra problems. As shown here, Student restates a problem, then analyzes the words in terms of its library of definitions and relations, sets up the proper equations and gives the solution. The machine has invented the symbol *G02521* to represent the *X* used in text of the article.

intelligence. I believe it will eventually be possible for programs, by resorting to analogical reasoning, to apply the experience they have gained from solving one kind of problem to the solution of quite different problems. Consider a situation in which a machine is presented with a problem that is too complicated for solution by any method it knows. Ordinarily to cope with such contingencies the computer would be programmed to split the problem into subproblems or subgoals, so that by solving these it can arrive at a solution to the main problem. In a difficult case, however, the machine may be unable to break the problem down or may become lost in a growing maze of irrelevant subgoals. If a machine is to be able to deal, then, with very hard problems, it must have some kind of planning ability—an ability to find a suitable strategy.

What does the rather imprecise word "planning" mean in this context? We can think of a definition in terms of machine operations that might be useful: (1) Replace the given problem by a similar but simpler one; (2) solve this analogous problem and remember the steps in its solution; (3) try to adapt the steps of the solution to solve the original problem. Newell and Simon have actually completed an experiment embodying a simple version of such a program. It seems to me that this area is one of the most important for research on making machine intelligence more versatile.

I should now like to give a third example of a program exhibiting intelligence. This program has to do with the handling of information written in the English language.

Since the beginnings of the evolution of modern computers it has been obvious that a computer could be a superb file clerk that would provide instant access to any of its information—provided that the files were totally and neatly organized and that the kinds of questions the computer was called on to answer could be completely programmed. But what if, as in real life, the information is scattered through the files and is expressed in various forms of human discourse? It is widely supposed that the handling of information of this informal character is beyond the capability of any machine.

Daniel Bobrow, for his doctoral research at M.I.T., attacked this problem directly: How could a computer be programmed to understand a limited range of ordinary English? For subject matter he chose statements of problems in high school algebra. The purely

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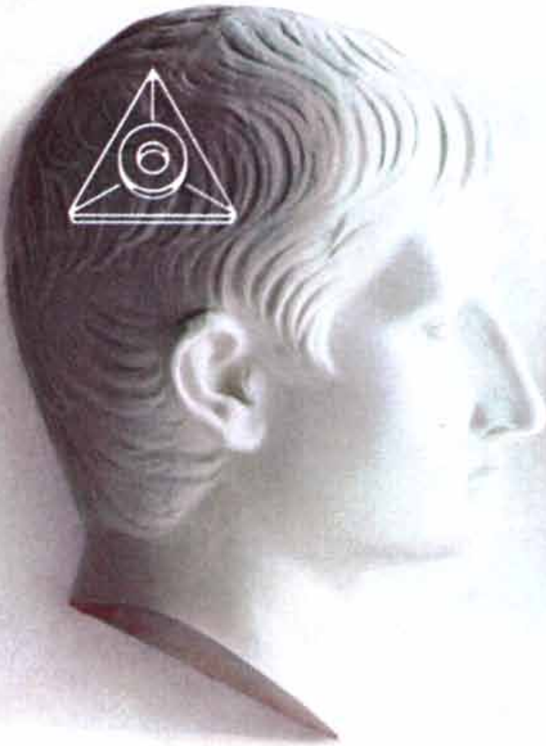

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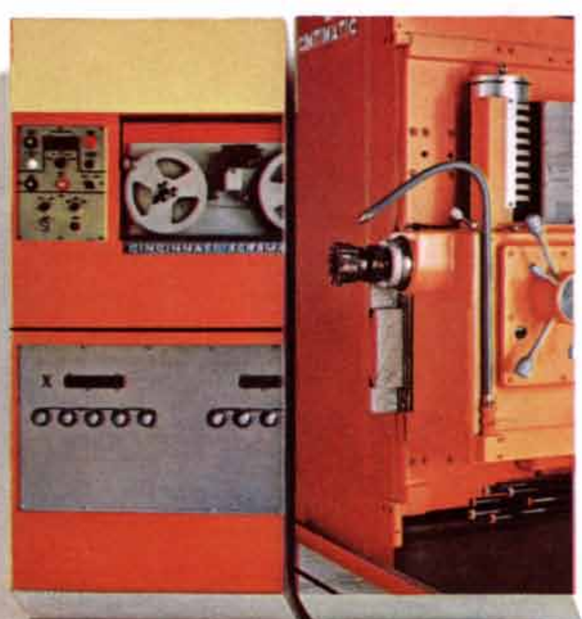

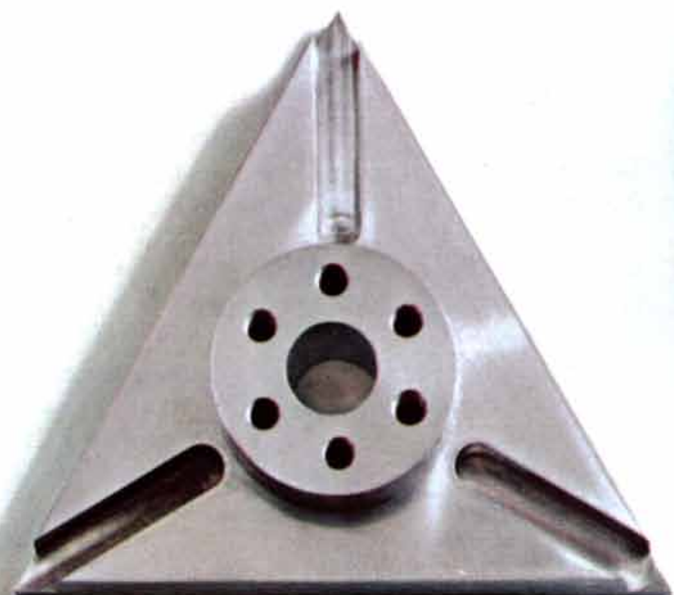

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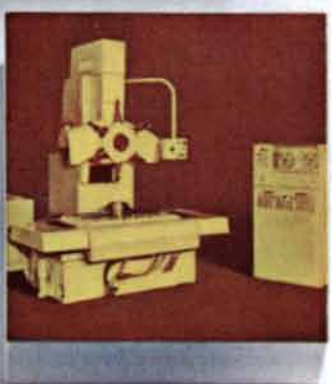

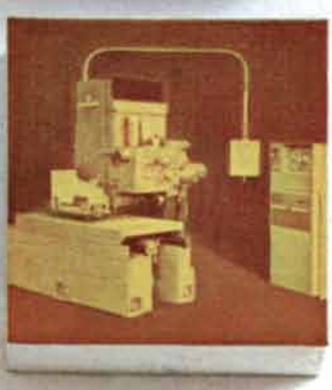

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6151 WEST CENTURY BOULEVARD, LOS ANGELES, CALIFORNIA 90045 (213) 670-9040 mathematical solution of these problems would be child's play for the computer, but Bobrow's main concern was to provide the computer with the ability to read the informal verbal statement of a problem and derive from that language the equations required to solve the problem. (This, and not solution of the equations, is what is hard for students too.)

The basic strategy of the program (which is named "Student") is this: The machine "reads in" the statement of the problem and tries to rewrite it as a number of simple sentences. Then it tries to convert each simple sentence into an equation. Finally it tries to solve the set of equations and present the required answer (converted back to a simple English sentence). Each of these steps in interpreting the meaning is done with the help of a library (stored in the core memory) that includes a dictionary, a variety of factual statements and several special-purpose programs for solving particular kinds of problems. To write the program for the machine Bobrow used the LISP programming language with some new extensions of his own and incorporated techniques that had been developed by Victor H. Yngve in earlier work on language at M.I.T.

The problems the machine has to face in interpreting the English statements are sometimes quite difficult. It may have to figure out the antecedent of a pronoun, recognize that two different phrases have the same meaning or discover that a necessary piece of information is missing. Bobrow's program is a model of informality. Its filing system is so loosely organized (although it is readily accessible) that new information can be added to the dictionary by dumping it in anywhere. Perhaps the program's most interesting technical aspect is the way it cuts across the linguist's formal distinction between syntax and semantics, thus avoiding problems that, it seems to me, have more hindered than helped most studies of language.

The illustrations on page 252 and on this page show three problems as they were solved by Student. The remarkable thing about Student is not so much that it understands English as that it shows a basic capacity for understanding anything at all. When it runs into difficulty, it asks usually pertinent questions. Sometimes it has to ask the person operating the computer, but often it resolves the difficulty by referring to the knowledge in its files. When, for instance, it meets a statement such as "Mary is twice as old as Ann was when Mary was as old as Ann is now," the program knows how to make the meaning of "was when" more precise by rewriting the statement as two simple sentences: "Mary is twice as old as Ann was *X* years ago. *X* years ago Mary was as old as Ann is now."

Bobrow's program can handle only a small part of the grammar of the English language, and its semantic dictionaries are quite limited. Yet even though it can make many kinds of mistakes within its linguistic limitations, it probably surpasses the average person in its ability to handle algebra problems stated verbally. Bobrow believes that, given a larger computer memory, he could make Student understand most of the problems that are presented in high school first-algebra textbooks.

As an example of another kind of intelligence programmed into a machine, a program developed by Lawrence G. Roberts as a doctoral thesis at M.I.T. endows a computer with some ability to analyze three-dimensional objects [*see illustration on page 246*]. In a single two-dimensional photograph of a solid object the program detects a number of the object's geometrical features. It uses these to form a description in terms of lines and then tries to analyze the figure as a composite of simpler building blocks (rectangular forms and prisms). Once the program has performed this analysis it can reconstruct the figure from any requested point of view, drawing in lines that

```
(THE PROBLEM TO BE SOLVED IS)
(THE GAS CONSUMPTION OF MY CAR IS 15 MILES PER GALLON . THE
DISTANCE BETWEEN BOSTON AND NEW YORK IS 250 MILES . WHAT IS
THE NUMBER OF GALLONS OF GAS USED ON A TRIP BETWEEN NEW YORK
AND BOSTON Q.)

(THE EQUATIONS TO BE SOLVED ARE)

(EQUAL G02556 (NUMBER OF GALLONS OF GAS USED ON TRIP BETWEEN
NEW YORK AND BOSTON))

(EQUAL (DISTANCE BETWEEN BOSTON AND NEW YORK) (TIMES 250 (MILES)))

(EQUAL (GAS CONSUMPTION OF MY CAR) (QUOTIENT (TIMES 15 (MILES))
(TIMES 1 (GALLONS))))

THE EQUATIONS WERE INSUFFICIENT TO FIND A SOLUTION

(USING THE FOLLOWING KNOWN RELATIONSHIPS)
((EQUAL (DISTANCE) (TIMES (SPEED) (TIME))) (EQUAL (DISTANCE)
(TIMES (GAS CONSUMPTION) (NUMBER OF GALLONS OF GAS USED))))

(ASSUMING THAT)
((DISTANCE) IS EQUAL TO (DISTANCE BETWEEN BOSTON AND NEW YORK))

(ASSUMING THAT)
((GAS CONSUMPTION) IS EQUAL TO (GAS CONSUMPTION OF MY CAR))

(ASSUMING THAT)
((NUMBER OF GALLONS OF GAS USED) IS EQUAL TO (NUMBER OF GALLONS
OF GAS USED ON TRIP BETWEEN NEW YORK AND BOSTON))

(THE NUMBER OF GALLONS OF GAS USED ON A TRIP BETWEEN NEW YORK
AND BOSTON IS  16.66 GALLONS)
```

MOMENTARILY STUMPED at finding unknowns for which it has no equations, Student makes a guess that two phrases describe the same thing and goes on to solve the problem.

```
(THE PROBLEM TO BE SOLVED IS)
(THE GROSS WEIGHT OF A SHIP IS 20000 TONS . IF ITS NET WEIGHT
IS 15000 TONS , WHAT IS THE WEIGHT OF THE SHIPS CARGO Q.)

THE EQUATIONS WERE INSUFFICIENT TO FIND A SOLUTION

TRYING POSSIBLE IDIOMS

(DO YOU KNOW ANY MORE RELATIONSHIPS AMONG THESE VARIABLES)

(GROSS WEIGHT OF SHIP)

(TONS)

(ITS NET WEIGHT)

(WEIGHT OF SHIPS CARGO)

yes
TELL ME

(the weight of a ships cargo is the difference between
the gross weight and the net weight)

THE EQUATIONS WERE INSUFFICIENT TO FIND A SOLUTION

(ASSUMING THAT)
((NET WEIGHT) IS EQUAL TO (ITS NET WEIGHT))

(ASSUMING THAT)
((GROSS WEIGHT) IS EQUAL TO (GROSS WEIGHT OF SHIP))

(THE WEIGHT OF THE SHIPS CARGO IS 5000 TONS)
```

LACKING INFORMATION with which to solve a problem, Student asks for help. The operator (typing in lowercase letters) provides the necessary relations but does not use the same words as the problem used, forcing literal-minded Student to make some assumptions.

```
((STUDENT    ($)   (/ (*S ORGPRB 1))                               *)
(*      ($)    (1 (FN TERPRI) (FN TERPRI) (FN TERPRI))             *)
(*      ((*P THE PROBLEM TO BE SOLVED IS))                         *)
(IDIOMS ($)                                                        *)
(*      (HOW OLD)   (WHAT)                                    IDIOMS)
(*      (IS EQUAL TO) (IS)                                    IDIOMS)
(*      (YEARS YOUNGER THAN)   (LESS THAN)                    IDIOMS)
(*      (YEARS OLDER THAN)   (PLUS)                           IDIOMS)
(*      (PERCENT LESS THAN)   (PERLESS)                       IDIOMS)
(*      (LESS THAN)   (LESSTHAN)                              IDIOMS)
(*      (THESE)   (THE)                                       IDIOMS)
(*      (MORE THAN)   (PLUS)                                  IDIOMS)
(*      (FIRST TWO NUMBERS)   (THE FIRST NUMBER AND THE
            SECOND NUMBER)                                    IDIOMS)
(*      (THREE NUMBERS)   (THE FIRST NUMBER AND THE SECOND
             NUMBER AND THE THIRD NUMBER)                     IDIOMS)
(*      (ONE HALF)  ( .5000)                                  IDIOMS)
(*      (TWICE)   (2 TIMES)                                   IDIOMS)
(*      (TWO NUMBERS)                                            SIM)
(*      ((* DOLLAR) $1)   (2 DOLLARS)                         IDIOMS)
(*      (CONSECUTIVE TO)   ((QUOTE 1) PLUS)                   IDIOMS)
(*      (LARGER THAN)   (PLUS)                                IDIOMS)
(*      (PER CENT)   (PERCENT)                                IDIOMS)
(*      (HOW MANY)   (HOWM)                                   IDIOMS)
(*      (SQUARE OF)   (SQUARE)                                IDIOMS)
(*      (($.1S) MULTIPLIED BY)   (TIMES)                      IDIOMS)
(*      (($.1S) DIVIDED BY)   (DIVBY)                         IDIOMS)
(*      (THE SUM OF)   (SUM)                                  IDIOMS)
(*      ($)   (/ (*S NONID 1))                                     *)
(WORDS  ($1)   0   (/ (*Q SHELF (FN GETDCT 1 DICT)))
            WORDS)
(*      ($)   ((*A SHELF))                                         *)
(THE    (THE THE)   (1)                                          THE)
(*      ($)   (/ (*S MARKWD 1))                                    *)
(*      (AS OLD AS)                                          AGEPROB)
(*      (AGE)                                                AGEPROB)
(*      (YEARS OLD)                                          AGEPROB)
(*      ($)   (/ (*D RETURN SENTENCE))                       BRACKET)
(SENTENCE   ($)   ((*N PROBLEM))                                   *)
(*      ($1)   0   (/ (*S FIND (*E 1)) (*D RETURN SENTENCE
            ))                                                OPFORM)
(QUIET  ($)                                                        *)
(SUBSTITUTIONS  ($)   ((FN TERPRI) (*A NONID))                     *)
(*      ((*P WITH MANDATORY SUBSTITUTIONS THE PROBLEM IS))
              *)
(TAGGING    ($)   ((FN TERPRI) (*A MARKWD))                        *)
(*      ((*P WITH WORDS TAGGED BY FUNCTION THE PROBLEM IS)
            )                                                      *)
```

BOBROW'S PROGRAM is written in a language, METEOR, that he developed from the established programming language LISP. A small part of the program is illustrated here.

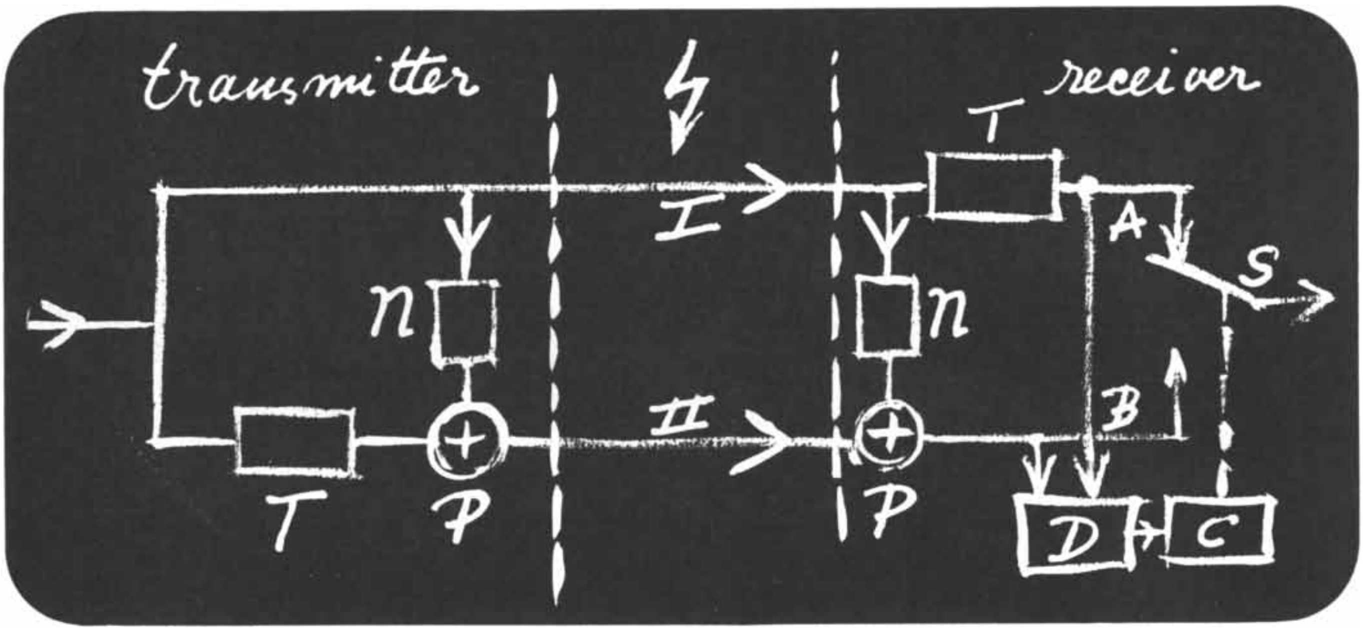
were originally hidden and suppressing lines that should not appear in the new picture. The program employs some rather abstract symbolic reasoning.

The exploration of machine intelligence has hardly begun. There have been about 30 experiments at the general level of those described here. Each investigator has had time to try out a few ideas; each program works only in a narrow problem area. How can we make the programs more versatile? It cannot be done simply by putting together a collection of old programs; they differ so much in their representation of objects and concepts that there could be no effective communication among them.

If we ask, "Why are the programs not more intelligent than they are?" a simple answer is that until recently resources—in people, time and computer capacity—have been quite limited. A number of the more careful and serious attempts have come close to their goal (usually after two or three years of work); others have been limited by core-memory capacity; still others encountered programming difficulties. A few projects have not progressed nearly as much as was hoped, notably projects in language translation and mathematical theorem-proving. Both cases, I think, represent premature attempts to handle complex formalisms without also somehow representing their meaning.

The problem of combining programs is more serious. Partly because of the very brief history of the field there is a shortage of well-developed ideas about systems for the communication of partial results between different programs, and for modifying programs already written to meet new conditions. Until this situation is improved it will remain hard to combine the results of separate research projects. Warren Teitelman of our laboratory has recently developed a programming system that may help in this regard; he has demonstrated it by re-creating in a matter of hours the results of some earlier programs that took weeks to write.

The questions people most often ask are: Can the programs learn through experience and thus improve themselves? Is this not the obvious path to making them intelligent? The answer to each is both yes and no. Even at this early stage the programs use many kinds of processes that might be called learning; they remember and use the methods that solved other problems; they adjust some of their internal characteristics for the best performance; they "associate" symbols that have been correlated in the past. No program today,



A says "yes", B says "no" - Who is right?

If A says "yes" and B says "no", then who is right? This riddle, reminiscent of the tales about King Solomon, is encountered in this twentieth century by those who are involved, in telecommunications, with error-correction by means of diversity.

At first sight the problem seems unsolvable: if two identical signals are transmitted and one of the signals received is disturbed, then the fact that perturbation is present can easily be detected, but how to know which one of the two signals is right and which is wrong?

A simple solution was found by Mr. Zegers from our laboratory. He observed that the riddle can be answered, if A is made to tell the truth somewhat longer than B.

In the system based on this principle the same information is sent over two parallel channels. In channel I the signal is delayed (T) at the receiving end, in channel II it is likewise delayed, but at the sender. Without perturbation, the signals A and B are equal and either of them may be delivered at the output. In case of a heavy disturbance in the transmission path (e.g. an interruption) the signals A and B at once show a discrepancy. This is detected by the detector D which starts a counter C. This in turn operates switch S in such a way that the reliable information stored in T is read out first. Then, just before the unreliable information is going to appear at point A, the switch is connected to B, where the information is reliable again if the perturbation has been shorter than the time interval T. After the switch has been in position B during T, it is returned to its original position and the system is ready for the elimination of the next disturbance.

For efficient operation of the system each perturbation in the transmission path must be detected at an early stage. For heavy disturbances, as mentioned above this is no problem: errors in channel-path II are detected in the receiver without time delay. However, in the case of single errors occurring in channel-path I only, D cannot detect these in time. For early detection of these errors too, the information of both channels is combined in the following manner: at the sender the information in channel I is made to operate on that in channel II via a branch, containing a n-stage shift register with internal forward connections and a modulo-two adder P. An identical combination used at the receiving end, cancels the influence of the two modulo-two adders as far as the information is concerned, but errors occurring in either channel will now affect the detector D in time.

With a system designed to eliminate error bursts of up to 1000 bits (as may occur e.g. in public telephone lines) it has been found that the probability of errors at the output may be decreased by a factor between 100 and 1000, depending on line conditions. A continuous stream of digital information can thus be transported over a heavily disturbed transmission path without the need of complex coding arrangements.

a monologue by
Mr. F. de Jager of
Philips Research
Laboratories.
Eindhoven,
the Netherlands.

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however, can work any genuinely important change in its own basic structure. (A number of early experiments on "self-organizing" programs failed because of excessive reliance on random trial and error. A somewhat later attempt by the Carnegie Institute group to get their General Problem Solver to improve its descriptive ability was based on much sounder ideas; this project was left unfinished when it encountered difficulties in communication between programs, but it probably could be completed with the programming tools now available.)

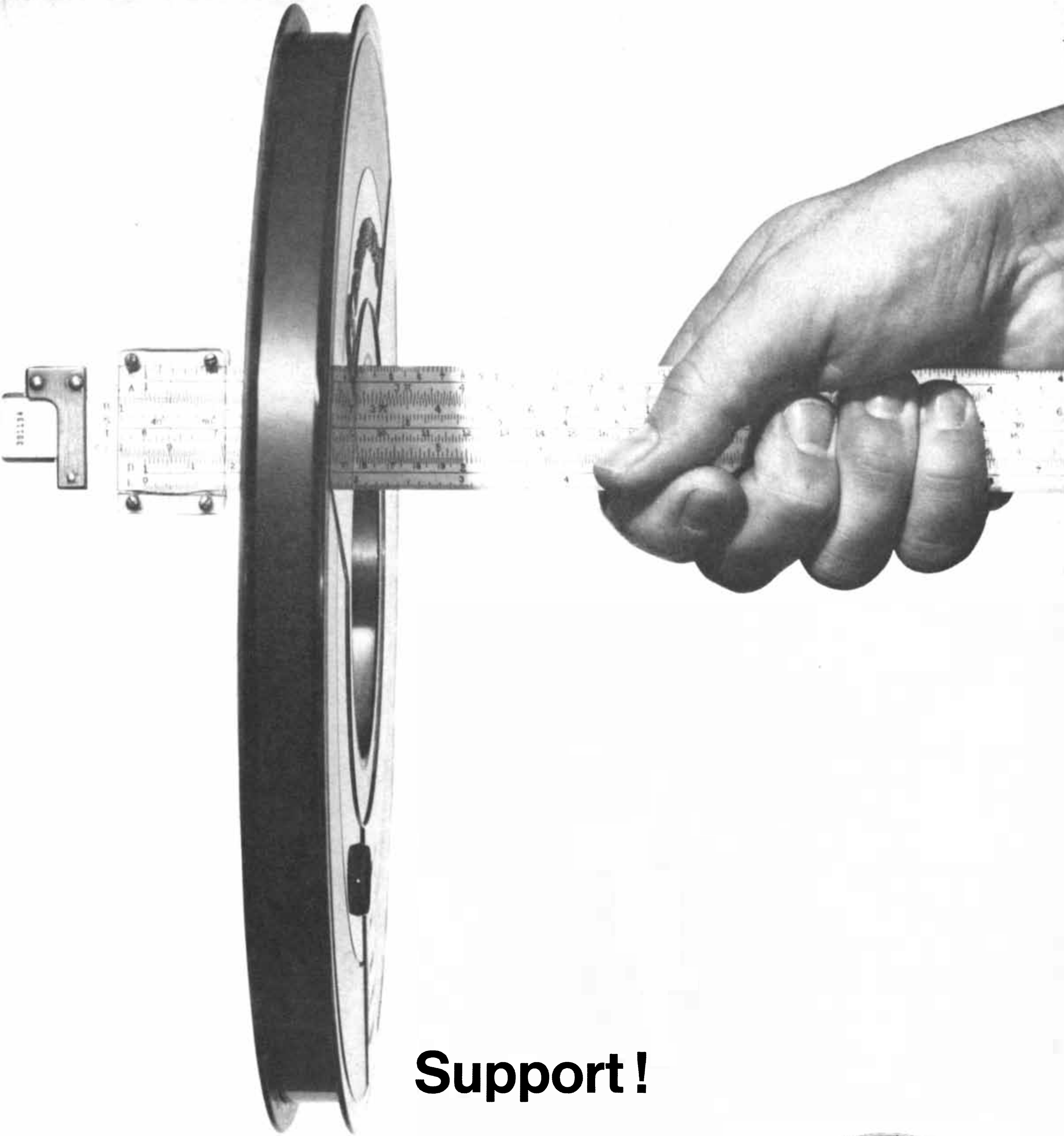
In order for a program to improve itself substantially it would have to have at least a rudimentary understanding of its own problem-solving process and some ability to recognize an improvement when it found one. There is no inherent reason why this should be impossible for a machine. Given a model of its own workings, it could use its problem-solving power to work on the problem of self-improvement. The present programs are not quite smart enough for this purpose; they can only deal with the improvement of programs much simpler than themselves.

Once we have devised programs with a genuine capacity for self-improvement a rapid evolutionary process will begin. As the machine improves both itself and its model of itself, we shall begin to see all the phenomena associated with the terms "consciousness," "intuition" and "intelligence" itself. It is hard to say how close we are to this threshold, but once it is crossed the world will not be the same.

It is reasonable, I suppose, to be unconvinced by our examples and to be skeptical about whether machines will ever be intelligent. It is unreasonable, however, to think machines could become *nearly* as intelligent as we are and then stop, or to suppose we will always be able to compete with them in wit or wisdom. Whether or not we could retain some sort of control of the machines, assuming that we would want to, the nature of our activities and aspirations would be changed utterly by the presence on earth of intellectually superior beings.

```
REMEMBER((
(PEOPLE IS THE PLURAL OF PERSON)
(FEET IS THE PLURAL OF FOOT)
(YARDS IS THE PLURAL OF YARD)
(FATHOMS IS THE PLURAL OF FATHOM)
(INCHES IS THE PLURAL OF INCH)
(SPANS IS THE PLURAL OF SPAN)
(ONE HALF ALWAYS MEANS  0.5  )
(THREE NUMBERS ALWAYS MEANS THE FIRST NUMBER AND THE SECOND
NUMBER AND THE THIRD NUMBER)
(FIRST TWO NUMBERS ALWAYS MEANS
THE FIRST NUMBER AND THE SECOND NUMBER)
(MORE THAN ALWAYS MEANS PLUS)
(THESE ALWAYS MEANS THE)
(TWO NUMBERS SOMETIMES MEANS ONE NUMBER AND THE
     OTHER NUMBER)
(TWO NUMBERS SOMETIMES MEANS ONE OF THE
       NUMBERS AND THE OTHER NUMBER)
(HAS IS A VERB)
(GETS IS A VERB)
(HAVE IS A VERB)
(LESS THAN ALWAYS MEANS LESSTHAN)
(LESSTHAN IS AN OPERATOR OF LEVEL 2)
(PERCENT IS AN OPERATOR OF LEVEL 2)
(PERCENT LESS THAN ALWAYS MEANS PERLESS)
(PERLESS IS AN OPERATOR OF LEVEL 2)
(PLUS IS AN OPERATOR OF LEVEL  2)
(SUM IS AN OPERATOR)
(TIMES IS AN OPERATOR OF LEVEL 1)
(SQUARE IS AN OPERATOR OF LEVEL 1)
(DIVBY IS AN OPERATOR OF LEVEL 1)
(OF IS AN OPERATOR)
(DIFFERENCE IS AN OPERATOR)
(SQUARED IS AN OPERATOR)
(MINUS IS AN OPERATOR OF LEVEL 2)
(PER IS AN OPERATOR)
(SQUARED IS AN OPERATOR)
(YEARS OLDER THAN ALWAYS MEANS PLUS)
(YEARS YOUNGER THAN ALWAYS MEANS LESS THAN)
(IS EQUAL TO ALWAYS MEANS IS)
(PLUSS IS AN OPERATOR)
(MINUSS IS AN OPERATOR)
(HOW OLD ALWAYS MEANS WHAT)
(THE PERIMETER OF $1 RECTANGLE SOMETIMES MEANS
TWICE THE SUM OF THE LENGTH AND  WIDTH OF THE RECTANGLE)
(GALLONS IS THE PLURAL OF GALLON)
(HOURS IS THE PLURAL OF HOUR)
(MARY IS A PERSON)
(ANN IS A PERSON)
(BILL IS A PERSON)
(A FATHER IS A PERSON)
(AN UNCLE IS A PERSON)
(POUNDS IS THE PLURAL OF POUND)
(WEIGHS IS A VERB)
))
REMEMBER ((
(DISTANCE EQUALS SPEED TIMES TIME)
(DISTANCE EQUALS GAS CONSUMPTION TIMES
NUMBER OF GALLONS OF GAS USED)
(1 FOOT EQUALS 12 INCHES)
(1 YARD EQUALS 3 FEET)
))
```

FILING SYSTEM for Student is loosely organized, with different kinds of information listed in an unordered dictionary. This makes it easy to add new information as needed.



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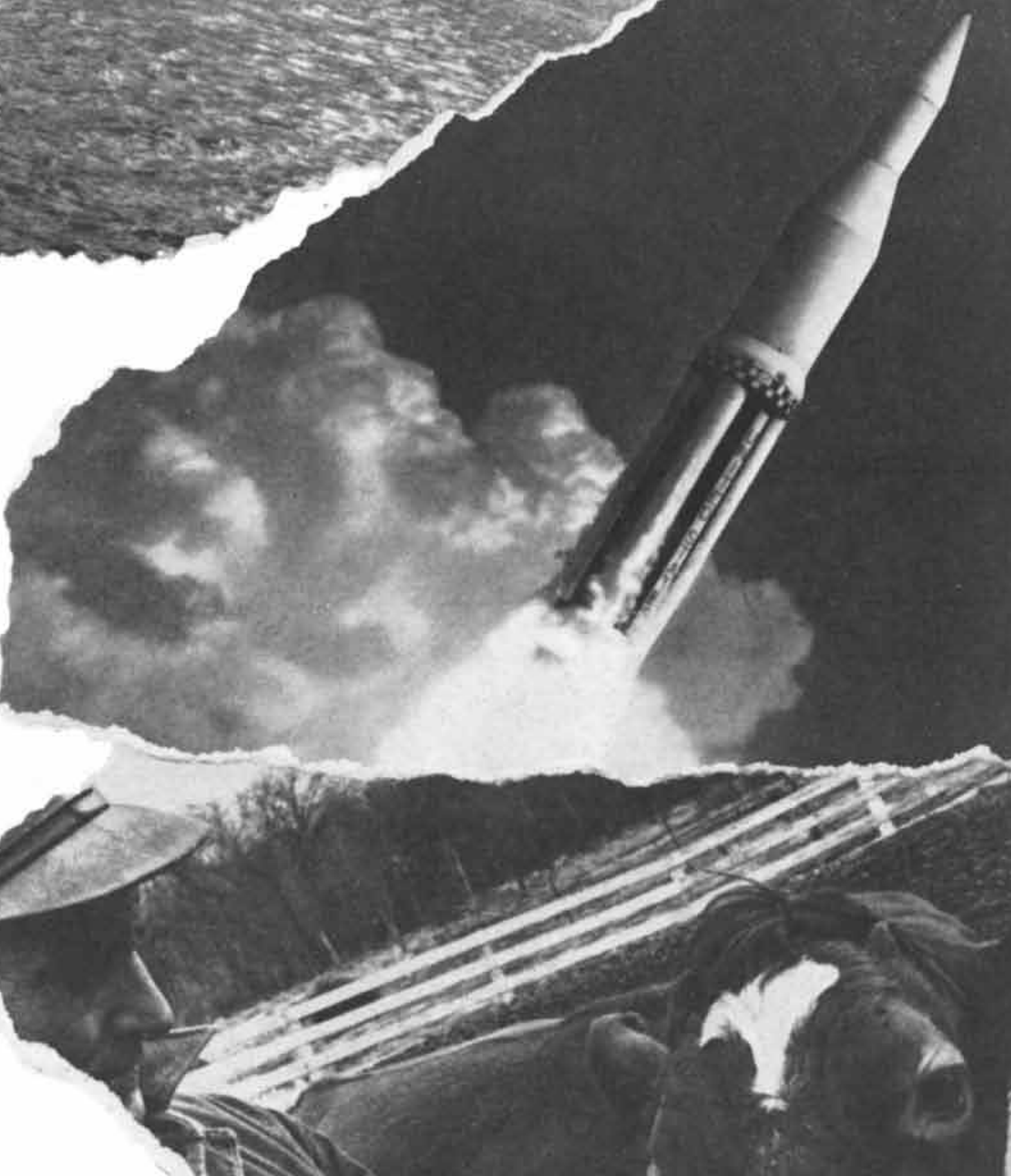

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MATHEMATICAL GAMES

The problem of Mrs. Perkins' quilt, and answers to last month's puzzles

by Martin Gardner

The mathematical and physical sciences edition of *The Proceedings of the Cambridge Philosophical Society*, one of the least frivolous of British journals, startled its readers in July, 1964, by publishing a lead article that bore the title "Mrs Perkins's Quilt." It was a technical discussion by the University of Cambridge mathematician J. H. Conway of one of the most useless but intriguing unsolved problems in recreational geometry.

The problem belongs to a large family of combinatorial questions that involve the packing of squares into larger squares. The best-known problem of this type is that of fitting a set of squares no two of which are alike into a larger square without any overlap or leftover space. If we think of the larger square as a lattice of unit squares to be divided along lattice lines into unequal squares, the smallest-known square that can be so divided has a side of 175 units. It can be cut into 24 unequal squares. The reader will find a picture of it on page 206 of *The 2nd Scientific American Book of Mathematical Puzzles & Diversions,* in a chapter by William T. Tutte explaining how he and his friends used electrical-network theory to find "squared squares" of this type.

The problem of Mrs. Perkins' quilt (it was named by the English puzzlist Henry Ernest Dudeney when he first introduced it) is the same as the problem considered by Tutte except for the elimination of one constraint: the smaller squares *need not be different*. A square lattice of any order n obviously can be divided into n^2 unit squares. The problem, however, is to determine the smallest number of squares into which it can be divided. This seems like a less constrained version of the Tutte problem, but the relaxed conditions do not appear to make the analysis any easier.

Mrs. Perkins' quilt is best approached by starting with the smallest sizes [*see illustration on opposite page*]. Solutions for squares of order 1 and order 2 are trivial. The order-3 square has the unique six-square pattern shown. (Rotations and reflections are not considered different.) Because 4 is a multiple of 2, the order-4 square can be divided, like the order-2, into four equal squares. But since this is merely a blown-up version of the order-2 pattern, we add a new proviso: the smaller squares must not have a common divisor. This leads to the minimum seven-square pattern shown, the minimum pattern that cannot be drawn on a lower-order square. Such a dissection is called a "prime dissection" of the square. Any solution for a square whose side is a prime will be a prime dissection, but for nonprime-order squares we must make sure that the dissection is prime, otherwise the minimum pattern will simply be a trivial repetition of the minimum pattern for the square whose order is the lowest factor of the square's side. Mrs. Perkins' problem can now be stated precisely as that of finding minimum prime dissections for squares of any order. Solutions for the first 12 squares are shown in the illustration.

When the square's order is in the Fibonacci series 1, 1, 2, 3, 5, 8, 13... (in which each term is the sum of the preceding two terms), a minimal *symmetrical* prime dissection is obtained by dividing it into squares with sides in the Fibonacci series. This produces minimum patterns for orders 1, 2, 3, 5 and 8, as shown, but breaks down for the order-13. The illustration on page 266 shows a symmetrical Fibonacci dissection for order-13. Readers are invited to see if they can reduce this from 12 to 11 squares, the minimum, by departing from symmetry; that is, by producing a pattern not superposable on its mirror image. The unique solution will be given next month.

What is desired, of course, is a general procedure by which minimum prime dissections can be found for squares of any order, and a formula that expresses the minimum number of squares as a function of the order of the larger square. Answers to both questions are nowhere in sight. Conway proved that the minimum prime dissection for a square of order n was equal to or greater than $\log_2 n$, and equal to or less than $6\sqrt[3]{n}+1$. In 1965 G. B. Trustrum of the University of Sussex published a proof that the least upper bound is $6 \log_2 n$. For higher-order squares this is an improvement over Conway's result, but it is still far from an explicit formula.

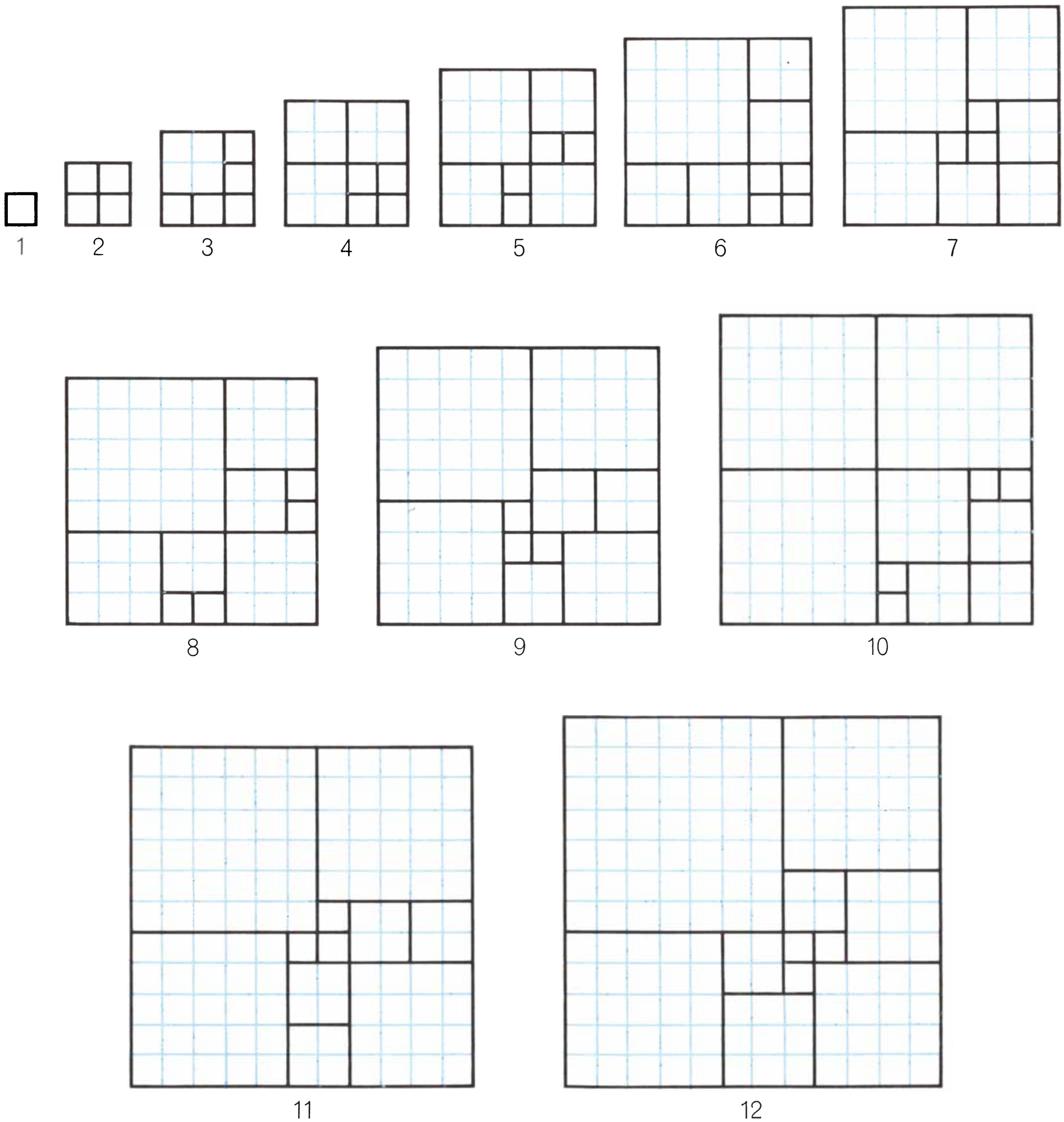
Leo Moser, head of the mathematics department at the University of Alberta, is cited in Conway's article for his early work on Mrs. Perkins' quilt. In more recent years Moser has turned to several other square-packing problems. Consider, for example, squares with sides that form the harmonic series $1/2 + 1/3 + 1/4 + 1/5\ldots$ The sum of these sides increases without limit. But the *areas* of these squares form a different series, $1/4 + 1/9 + 1/16 + 1/25\ldots$, that converges, surprisingly, on the limit $(\pi^2/6) - 1$ (surprising because of that unexpected appearance of pi). This is a little more than .6. Moser first asked himself: Can this infinite set of squares be fitted, without overlap, inside a unit square? The answer is yes. The illustration on page 269 shows his simple way of doing it. The square is first divided into strips with widths of 1/2, 1/4, 1/8... Because this series has the limit sum of 1, an infinity of such strips can be placed inside the unit square. Within each strip, squares are placed in descending order of size, starting on the left with a square that fills that end of the strip. In this way the infinite set of squares is comfortably accommodated, with a trifle less than .4 of the large square remaining uncovered. In a paper not yet published Moser and his collaborator J. W. Moon, also at the University of Alberta, push the problem to its ultimate. They show that the infinite set of squares can be fitted into a square of side 5/6 but into no smaller square. The paper contains other related results, including an elegant proof that any set of squares with a combined area of 1 can be packed without overlap into a square of side 2.

Among the many unsolved problems that concern the packing of squares into a larger square, one of the most infuriating is an unpublished problem proposed a few years ago by Richard B. Britton of Carlisle, Mass. He had read Tutte's article in this department on squaring the square with unequal squares and wondered if it would be possible to divide a square into smaller squares with sides in serial order 1, 2, 3, 4, 5... This would be possible, of course, only if the partial sum of the corresponding series of areas, $1 + 4 + 9 + 16 + 25 \ldots$, ever reaches a number that is itself a square. This does not happen until the first 24 square numbers have been added. The sum of $1^2 + 2^2 + 3^2 + \ldots + 24^2$ is 4,900, which is 70^2. Curiously, this never happens again.

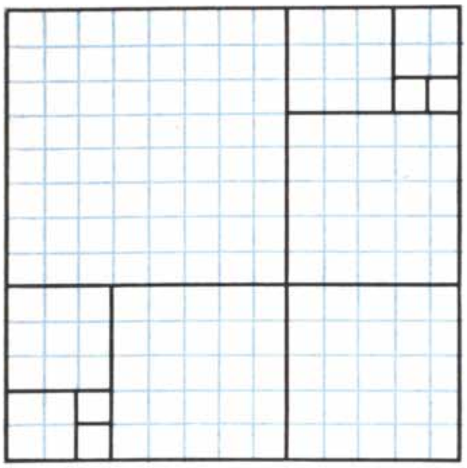
The discovery of the uniqueness of 4,900 has an interesting history that involves a type of three-dimensional "figurate" number called a "pyramidal number." Pyramidal numbers are the cardinal numbers of sets of cannonballs that can be stacked into four-sided pyramids with no balls left over. Since each layer of such a pyramid is a square of balls, starting with one on top, then a layer of four, then a layer of nine, and so on, it is easy to see that a pyramidal number must be a partial sum of the series $1^2 + 2^2 + 3^2 + \ldots + n^2$. The formula for such a number can be written in this form:

$$\frac{n\,(n+1)\,(2n+1)}{6}.$$

An old puzzle asked for the smallest number of cannonballs that will form a four-sided pyramid and can also be rearranged flat on the ground to form a perfect square. In algebraic terms the problem asked for the smallest positive



Solutions to the quilt problem for the first 12 squares



13

Symmetrical pattern for order-13 square

integral values of m and n that satisfy the Diophantine equation

$$\frac{n\,(n+1)\,(2n+1)}{6} = m^2\,.$$

The French mathematician Edouard Lucas, and later Dudeney, both conjectured that $n = 24$, $m = 70$ were the only positive integers that satisfied this equation, other than the trivial case of $n = 1$, $m = 1$. Put another way, 4,900 is the only number greater than 1 that is both square and pyramidal. It was not until 1918 that G. N. Watson (in *Messenger of Mathematics,* New Series, Vol. 48, pages 1–22) gave the first proof that this was indeed the case.

We know, therefore, that if a square checkerboard can be divided along lattice lines into squares with sides in the 1, 2, 3... series, it must be the order-70 board. Although I know of no proof that this is impossible, the work of Tutte and others makes it extremely unlikely, and perhaps an impossibility proof would not be hard to find. The question now arises (and this is Britton's proposed problem): What is the largest area of the order-70 square that *can* be covered by squares taken from the set of 24 squares? Of course, not all the 24 squares can be used. It is assumed that no square overlaps the border of the order-70 square and that no two covering squares overlap each other.

The answer is not known and I call on readers for help. The problem can be worked on by outlining an order-70 square on graph paper that has a matrix fine enough to make it possible, or one can paste down overlapping graph paper of larger mesh to make an order-70 square with unit squares of, say, a quarter-inch on the side. The covering squares can be cut from thin cardboard. (It is not necessary to include the three smallest squares, which are too tiny to work with.) The best strategy is to place large squares first. At the end there are almost certain to be holes into which it will be obvious that the 1-, 2- and 3-squares will fit.

Once you start pushing cardboard squares here and there over the order-70 square you are likely to get hooked on the problem. It has a peculiar fascination much like the challenge of packing as much as you can into a trunk or suitcase, but it has more mathematical precision. The exposed area is easily reduced to fewer than 200 unit squares. With ingenuity this can be chopped down to fewer than 150. Please send me your best result, with your name written legibly and the number of uncovered unit squares prominently indicated so that solutions can be evaluated quickly. I cannot reply to those who send patterns, but after a suitable lapse of time I shall publish the best result received.

Last month's science teasers are answered as follows:

1. When the sand is at the top of the hourglass, a high center of gravity tips the glass to one side. (The top and bottom of the hourglass are slightly convex to allow this.) The resulting friction against the side of the cylinder is sufficient to keep it at the bottom of the cylinder. After enough sand has flowed down to make the hourglass float upright, the loss of friction enables it to rise.

If the hourglass is a trifle heavier than the water it displaces, the toy operates in reverse. That is, the hourglass normally rests at the bottom of the cylinder; when the cylinder is turned over, the hourglass stays at the top, sinking only after the transfer of sand has eliminated the friction. Shops in Paris carry the toy in both versions and in a combined version with two cylinders side by side so that as the hourglass goes up in one it sinks in the other.

2. When an iron doughnut expands with heat, it keeps its proportions, therefore the hole also gets larger. The principle is at work when an optician removes a lens from a pair of glasses by heating the frame or a housewife heats the lid of a jar to loosen it.

3. Insert toothpick A between the cardboard horseshoe and toothpick B and move the horseshoe just enough to let the end of toothpick B come to rest on toothpick A [*see top drawing in illustration on page 270*]. Maneuver the end of B under the horseshoe and then lift shoe and toothpick, balancing them as shown in the bottom drawing.

4. The truck driver is wrong. The weight of a closed compartment containing a bird is equal to the weight of the compartment plus the bird's weight except when the bird is in the air and has a vertical component of motion that is accelerating. Downward acceleration reduces the weight of the system, upward acceleration increases it. If the bird is in free fall, the system's weight is lowered by the full weight of the bird. Horizontal flight, maintained by wing-flapping, alternates small up and down accelerations. Two hundred birds, flying about at random inside the panel truck, would cause minute, rapid fluctuations in weight, but the overall weight of the system would remain virtually constant.

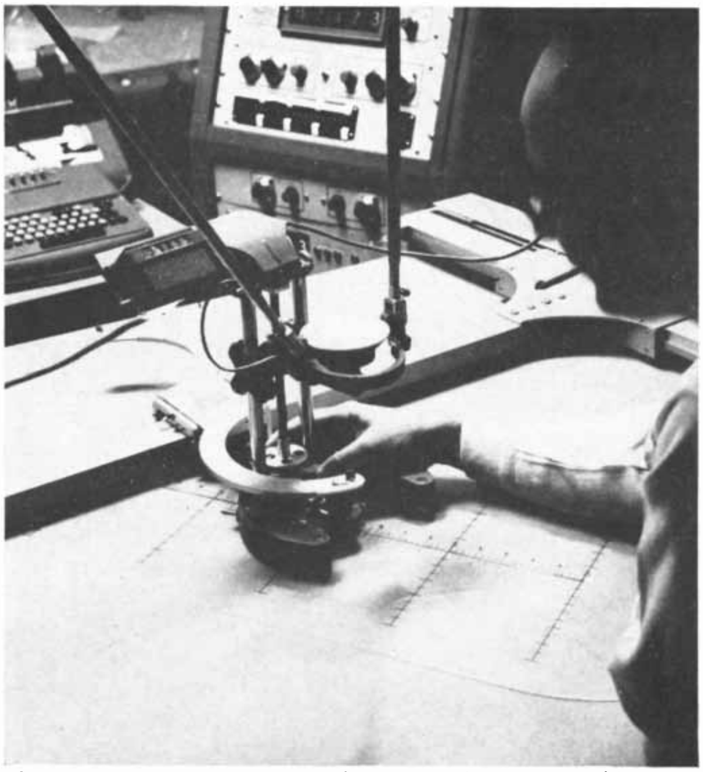
5. The cork floats at the center of the surface of the water in the glass only when the glass is filled a bit above its brim. The water's surface tension maintains the slightly convex surface.

6. On Lewis Carroll's "boat carriage," each pair of oval wheels, on opposite sides of the same axle, turns so that at all times the long axes of the ovals are at right angles to each other. This produces the "roll." If on each side of the carriage the two wheels also had their long axes at right angles, the carriage would neither pitch nor roll. It would simply move up and down, first on two diagonally opposite wheels, then on the other two. However, by gearing the front and back wheels so that on each side of the carriage the two wheels have their long axes at 45-degree angles, the carriage can be made to pitch and roll nicely, with single wheels leaving the ground in a four-beat sequence that is repeated as the carriage moves forward.

7. Oil floats on vinegar. To pour the oil Mr. Smith had only to tip the bottle. To pour vinegar he corked the bottle, inverted it, then loosened the cork just enough to let the desired amount of vinegar dribble out.

8. Touch the end of one bar to the middle of the other. If there is magnetic attraction, the touching end must be on the magnetized bar. If not, it is on the unmagnetized bar.

9. The water level stays the same. An ice cube floats only because its water has expanded during crystallization; its weight remains the same as the weight of the water that formed it. Since a floating body displaces its weight, the melted ice cube will provide the same



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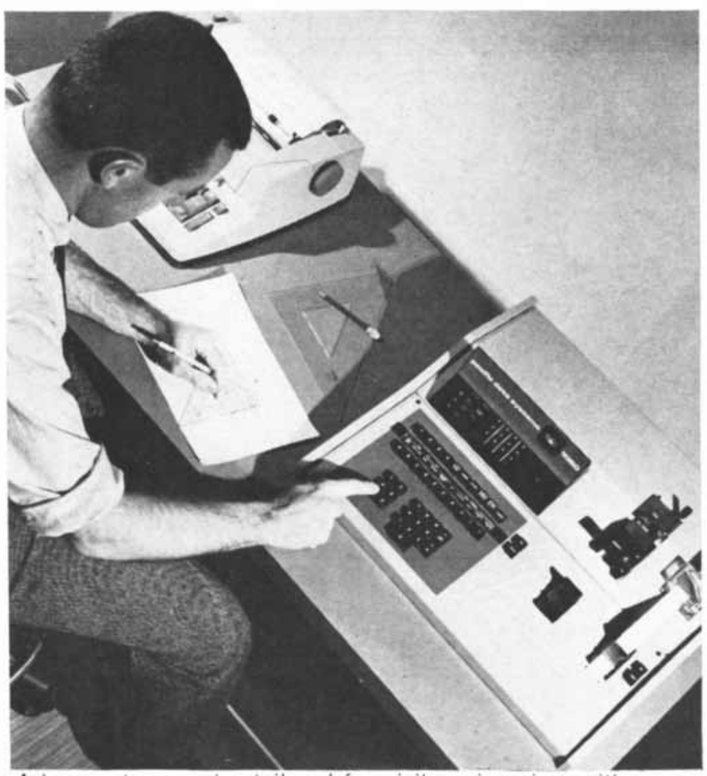

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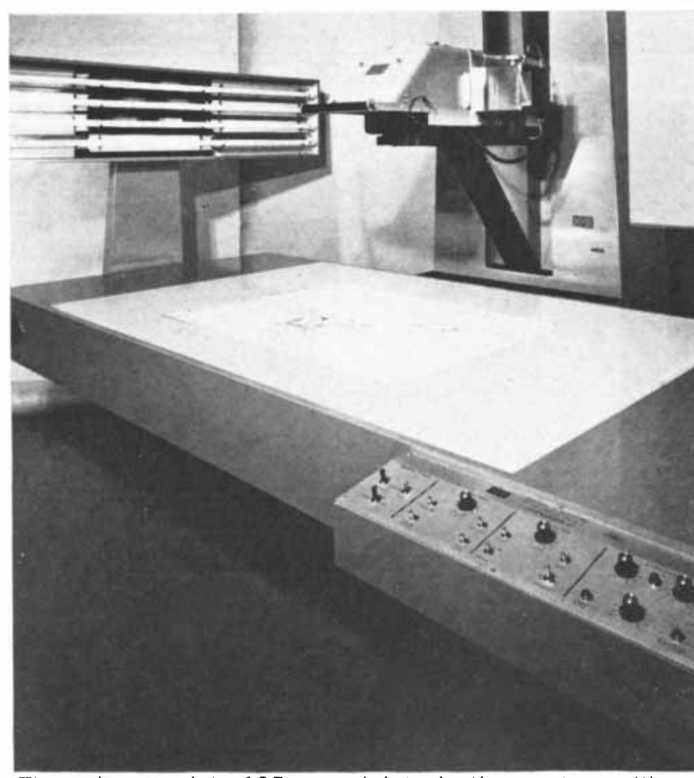

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amount of water as the volume of water it displaced when frozen.

10. The acrobat first ties the lower ends of the ropes together. He climbs rope *A* to the top and cuts rope *B*, leaving enough rope to tie into a loop. Hanging in this loop with one arm through it, he cuts rope *A* off at the ceiling (taking great care not to let it fall!) and then passes the end of *A* through the loop and pulls the rope until the middle of the tied-together ropes is at the loop. After letting himself down this double rope he pulls it free of the loop, thereby obtaining the entire length of *A* and almost all of *B*.

11. The top of the shadow of a man walking past a street light moves faster than the man, but it maintains a constant speed regardless of its length.

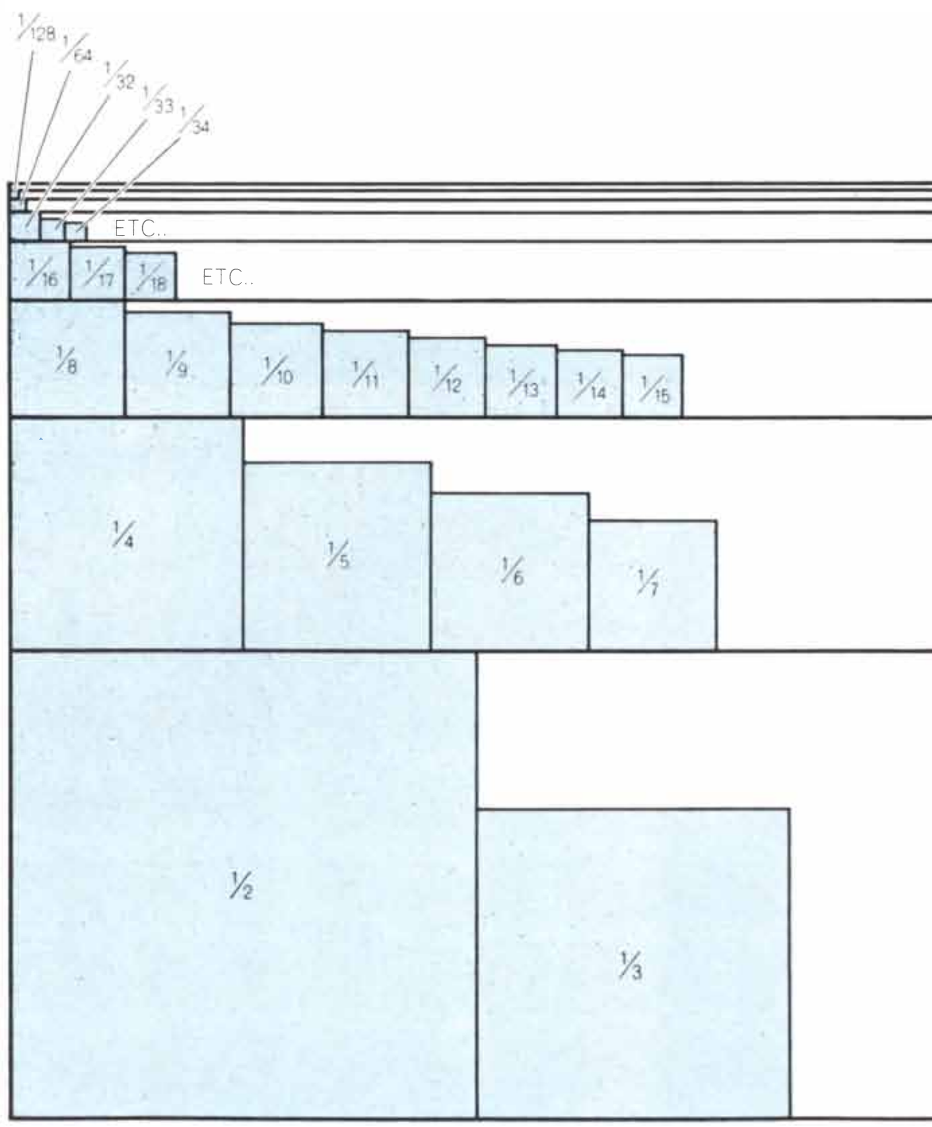
12. A quantity of water flows over the first winding of the hose to fall to the bottom and form an air trap. The trapped air prevents any more water from entering the first loop of the hose.

13. To remove the egg, tip back your head, hold the bottle upside down with the opening at your lips and blow vigorously into it. When you take the bottle from your mouth, the compressed air will pop the egg out through the neck of the bottle.

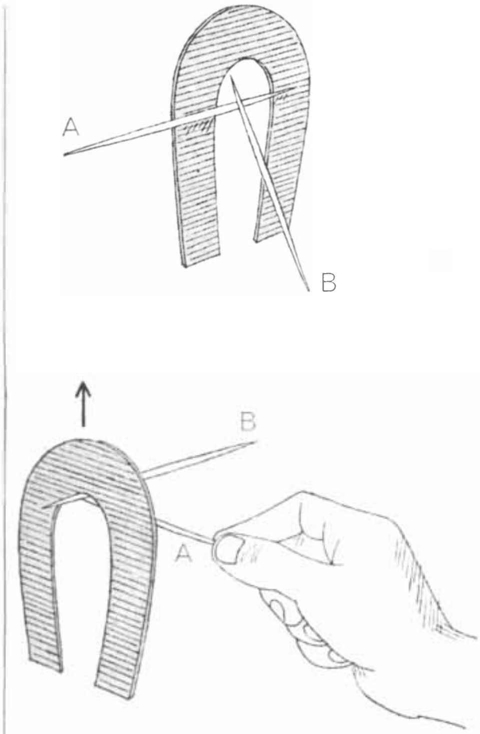
14. The nuts and bolts inside the toy ship displace an amount of water equal to their *weight*. When they sink to the bottom of the tub, they displace an amount equal to their *volume*. Since each piece weighs considerably more than the same volume of water, the water level in the tub is lowered after the cargo is dumped.

15. As the closed car accelerates forward, inertial forces send the air in the car backward. This compresses the air behind the balloon, pushing it forward. As the car rounds a curve, the balloon, for similar reasons, moves *into* the curve.

16. Zero gravity prevails at all points inside the hollow asteroid. For an explanation of how this follows from gravity's law of inverse squares see



Packing an infinite set of squares into a unit square



Solution to horseshoe puzzle

Hermann Bondi's Anchor paperback *The Universe at Large,* page 102.

17. A bird cannot fly at all on the airless moon.

18. If the Compton tube is on an east-west vertical plane and is then inverted along its horizontal east-west axis, Coriolis forces start its liquid circulating counterclockwise as you face the tube looking north. This happens because before the inversion the liquid at the top of the tube is moving east around the earth's center at a faster speed than the liquid at the bottom, since the earth's rotation carries it along a circular path of larger circumference. Flipping the tube brings this faster-moving liquid to the bottom and the slower-moving liquid to the top, setting up the slow counterclockwise circulation, which continues for hours. The strength of this circulation diminishes as the plane of the tube deviates from east-west, reaching zero when the plane is north-south. One can therefore determine east and west by flipping the tube in different orientations until a circulating force of maximum strength is obtained.

19. The bowl increases in weight by the amount of liquid displaced by the dunked fish.

20. Pulling the lower pedal of the bicycle backward causes the pedal to rotate in a way that normally would drive the bicycle forward, but since the brakes are not being applied the bicycle is free to move back with the pull. The

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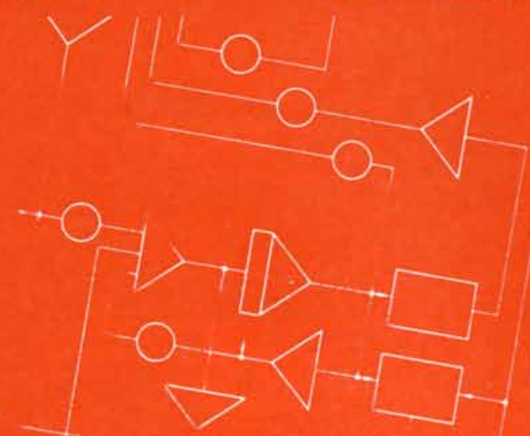
$$\frac{dq}{d} = -0.4647f \quad V \cdot \alpha \quad -0\ 362$$

$$\frac{dr}{} = q - \frac{d\alpha}{dt}$$



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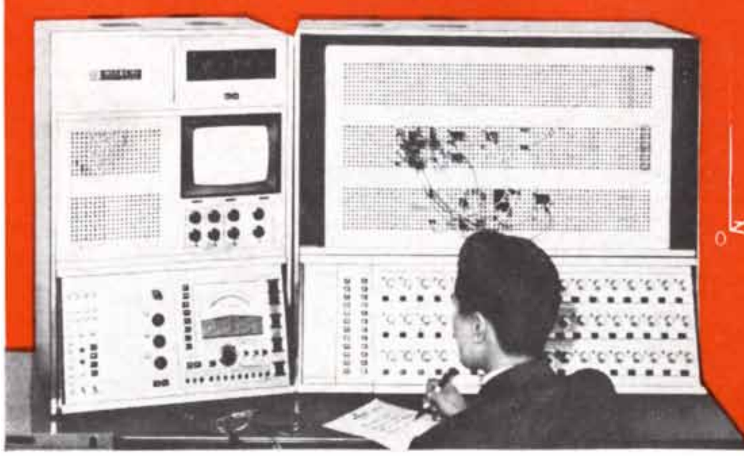

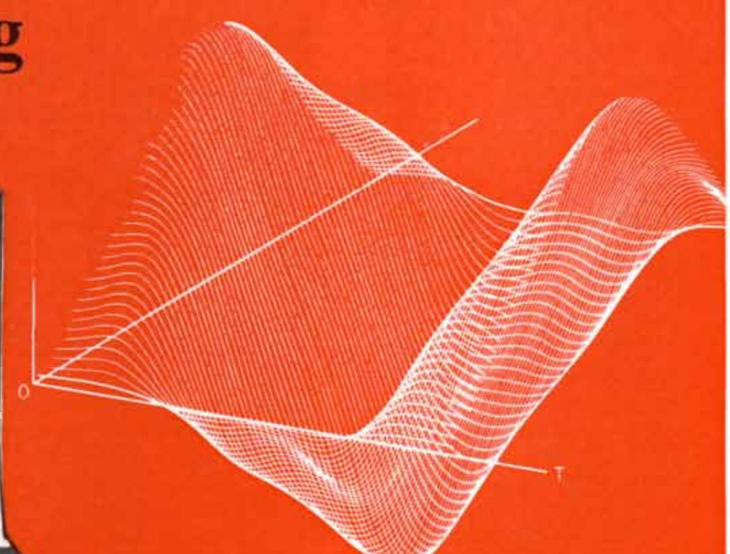

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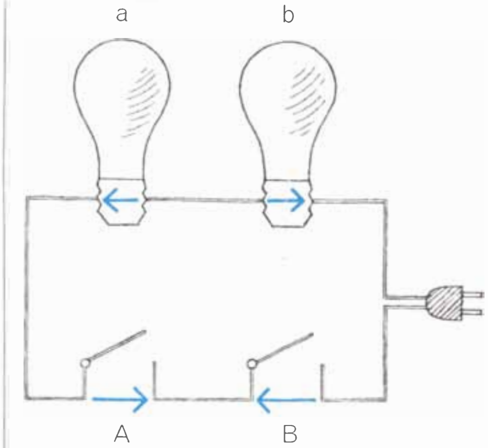


Solution to electrical paradox

large size of the wheels and the small gear ratio between the pedal and the wheel sprockets is such that the bicycle moves backward. The pedal moves back also with respect to the ground, although it moves forward with respect to the bicycle. When it rises high enough, the brake sets and the bicycle stops. Readers who do not believe all this will simply have to get a bicycle and try it.

21. A rowboat *can* be moved forward by jerking on a rope attached to its stern. In still water a speed of several miles per hour can be obtained. As the man's body moves toward the bow, friction between boat and water prevents any significant movement of the boat backward, but the inertial force of the jerk is strong enough to overcome the resistance of the water and transmit a forward impulse to the boat. The same principles apply when a boy sits inside a carton and scoots himself across a waxed floor by rapid forward movements inside the box. No such "inertial space drive" is possible inside a spaceship because the near vacuum surrounding the ship offers no resistance.

22. A pound of \$10 gold pieces contains twice as much gold as half a pound of \$20 gold pieces, therefore it is worth twice as much.

23. Concealed inside the base of each bulb and the base of each on-off switch is a tiny silicon rectifier that allows the current to flow through it in only one direction. The circuit is shown above, the arrows indicating the direction of current flow permitted by each rectifier. If the current is moving so that a rectifier in the base of a bulb will carry it, the rectifier steals the current and the bulb remains dark. It is easy to see that each switch turns on and off only the bulb whose rectifier points in the same circuit direction as the rectifier in the switch.

THE AMATEUR SCIENTIST

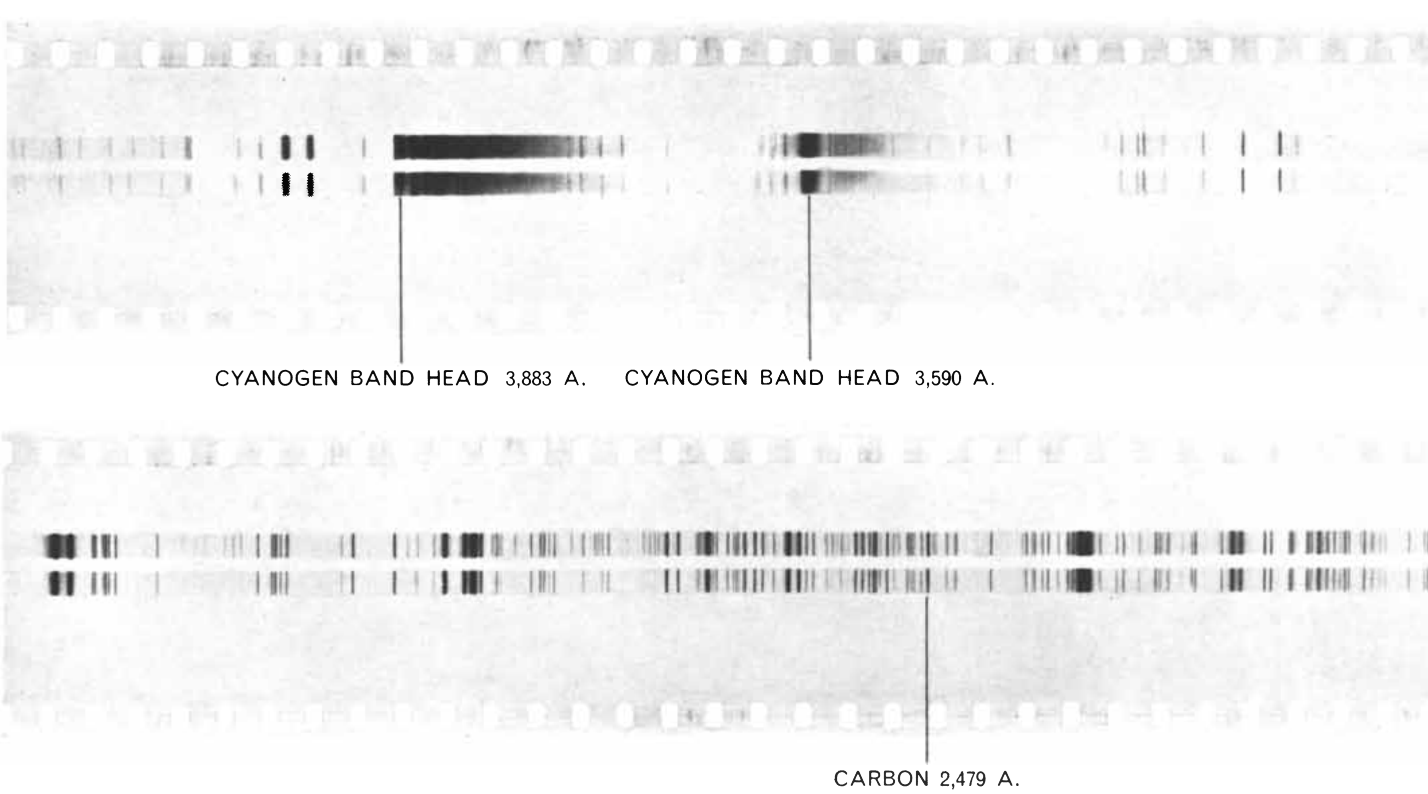
On the making of an inexpensive diffraction-grating spectrograph

Conducted by C. L. Stong

Light from any luminous gas or vapor contains in its constituent colors a remarkable amount of information about the source. The colors indicate the chemical elements in the gas or vapor, the proportions of the elements, their atomic structure, their temperature, their motion toward or away from the observer and the strength of the surrounding magnetic field. This information eludes the unaided eye. To obtain the information experimenters use the spectrograph, an instrument that sorts light waves according to length and displays the result as a band of parallel lines resembling a fence of randomly spaced pickets arrayed in the color sequence of the rainbow. During the century since Gustav Kirchhoff and Robert Bunsen constructed the first practical spectroscope the characteristic pattern of lines emitted by nearly all the naturally occurring chemical elements has been measured and catalogued. Upward of a million lines have been observed but no two elements have ever been found to have a single line in common, although some are very close together.

Few amateurs own spectrographs, because instruments of reasonably good quality cost several hundred dollars. It is now possible, however, for an amateur to build an inexpensive spectrograph. Sam Epstein, chief chemist of the Federated Metals Division of the American Smelting and Refining Company in Los Angeles, has recently designed an instrument of excellent quality that can be built at home for less than $100. With it experimenters can readily identify approximately 70 chemical elements listed in the periodic table, sometimes even if their presence in a mixture of substances amounts to no more than a few parts per million. In addition the apparatus can be adapted for use with telescopes in analyzing phenomena on the sun, although its size limits its application to permanently mounted telescopes.

Epstein writes: "Physically all spectrographs consist essentially of three elements: a narrow slit, through which passes the light that is to be analyzed; a dispersing element, which may be either a glass prism or a grating that consists of a pattern of closely and uniformly spaced lines ruled on either a transparent or a reflecting surface, and a camera. For a number of years all spectrographs were based on an optical principle first described by Isaac Newton. When a narrow beam of sunlight passes through a glass prism in a darkened room, a pattern of rainbow colors forms on the opposite wall. In the instrument based on this principle a narrow beam is formed by passing light rays through a slit. Diverging rays from



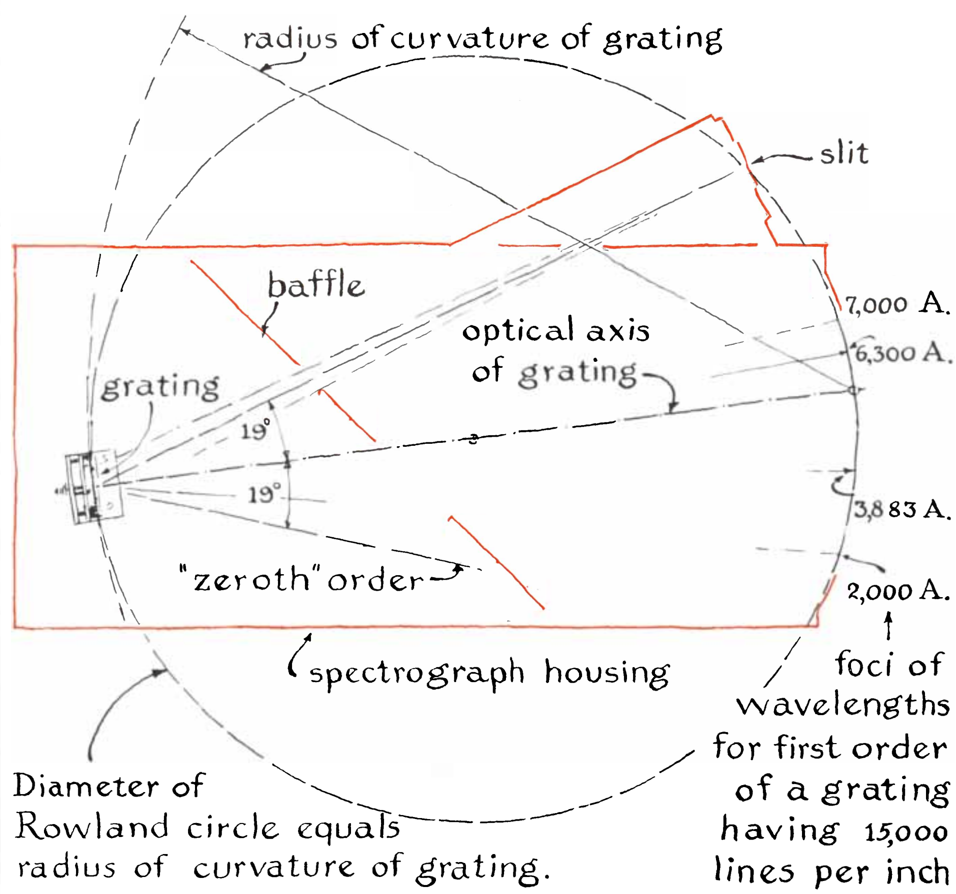
Spectrogram of graphite made with Sam Epstein's homemade spectrograph. Key bands are identified in angstrom units the slit are made parallel by a lens; after passing through the prism they are focused on a screen by a second lens. The screen can be replaced by photographic film or the colors can be observed directly with a small telescope. The resulting spectrum consists of a band of adjacent colored lines that are images of the slit.

"Good instruments of this type are difficult to build because they require lenses of high optical quality that focus all colors equally. Moreover, the resolving power, or ability of the instrument to separate the closely spaced lines, increases with the size of the prism, and so does the cost. Glass is opaque to ultraviolet rays—those wavelengths shorter than 3,300 angstrom units constituting the part of the spectrum that is most useful for identifying unknown atoms.

"For these reasons gratings made by ruling lines on the surface of a concave mirror have largely replaced prisms in spectrographs. Gratings used in general-purpose spectrographs may have 30,000 or more evenly spaced rulings cut on a surface of polished metal only an inch wide and two inches long. Such gratings are costly. In recent years, however, methods have been developed for making plastic duplicates of the rulings. These replicas are then mounted on the concave surface of aluminized glass mirrors. As assembled in the instrument the grating receives light either directly from the slit or after reflection by a mirror and focuses the lines of color on a photographic film or plate. All rays are reflected without significant absorption. The resulting spectrum spans some 30 octaves, including the single octave of light.

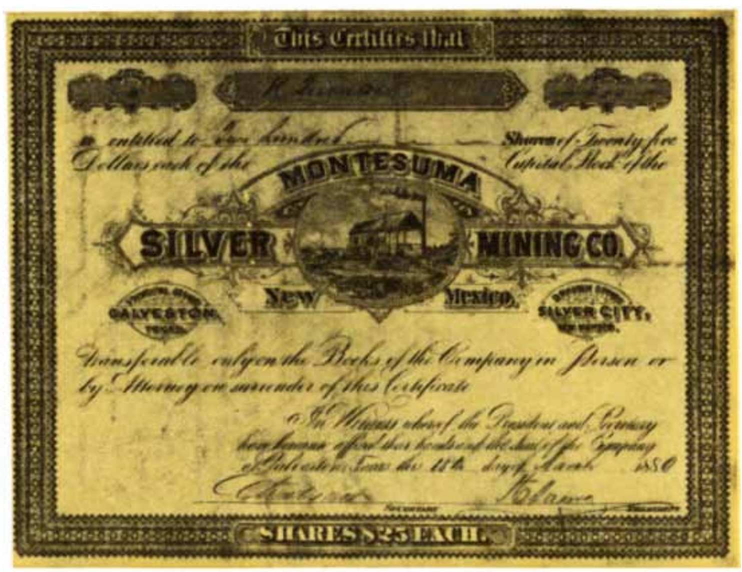
"An easily constructed spectrograph that can serve as a powerful analytical tool in many fields of experimentation is based on a discovery of the physicist Henry A. Rowland. In the 19th century he observed that if a concave grating, a slit and photographic film are placed on a circle equal in diameter to the radius of curvature of the grating, the diffracted rays come to a focus on the film.

"Unlike the prism, the grating presents the spectrum simultaneously at a number of positions. At one point on the circle the undispersed image of the slit appears. This narrow image is flanked on both sides by a series of spectra, the ends of which may overlap more or less depending on the design of the grating and the angle at which the incoming rays impinge on the grating. These images are known as spectral orders, the undispersed image being designated as the "zeroth" order and the flanking spectra as the first, second and third orders and so on. In general



A Rowland circle

This is a fake.



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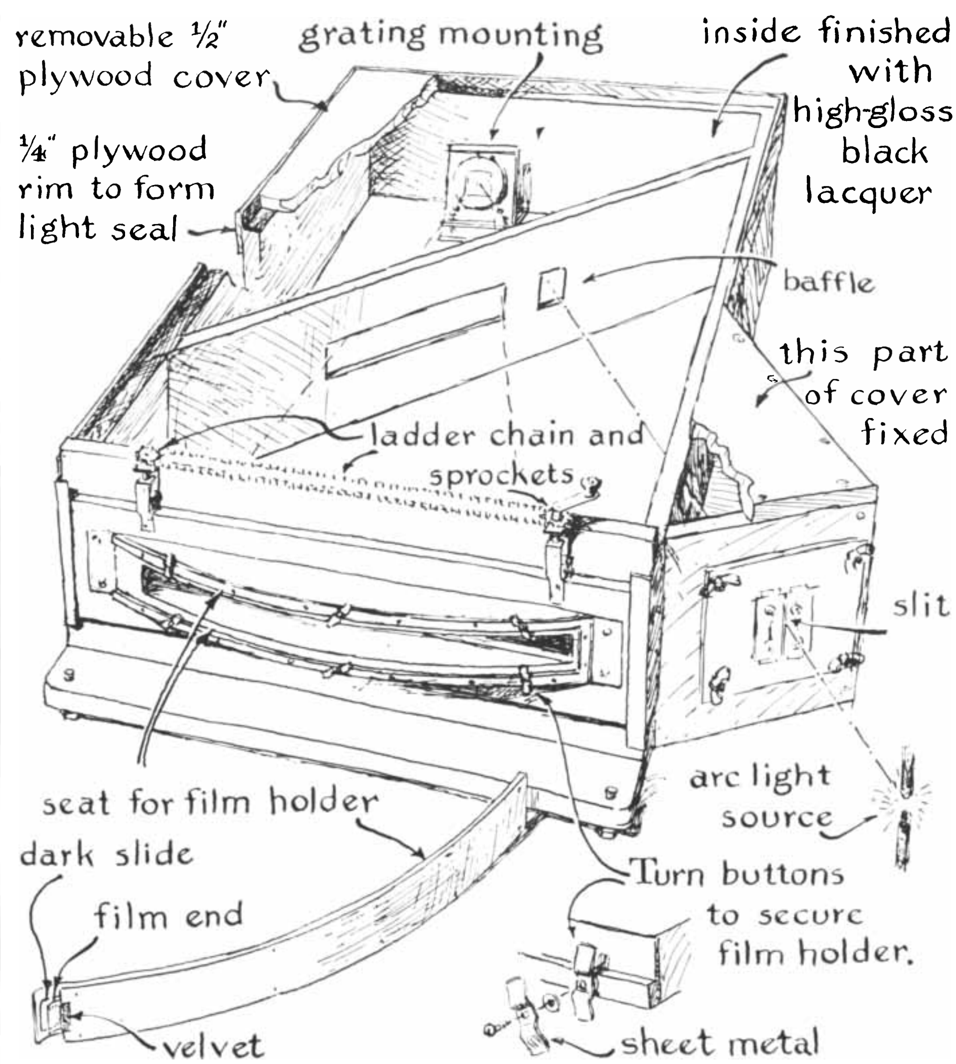


General view of the spectrograph

the spectrum of the first order is the shortest and brightest. By cutting the rulings at a certain angle, however, it is possible to construct gratings that reflect most of the light into a particular order. The spacing between the spectral lines increases in proportion to the increased length of the higher orders.

"If the spacing between the rulings of the grating is known, as well as the angle at which incoming light rays fall on the grating, the angular position at which light of any color will come to a focus on the circle can be computed simply. An example can be given for a grating ruled with 15,000 lines per inch. A wave of light 6,300 angstroms in length falling on the grating at an angle of 19 degrees with a line perpendicular to the face of the grating will be diffracted at an angle of 2.9 degrees from the perpendicular and on the same side of it. A wavelength of 2,300 angstroms striking the grating at an angle of 19 degrees will be diffracted at 10.9 degrees on the opposite side of the perpendicular.

"If the 15,000-line grating is supported on the face of a concave mirror with a radius of curvature of 100 centimeters, these two lines, which span 4,000 angstroms, will be separated by a distance of 25.4 centimeters at the plane of the film. That is about 16 angstroms per millimeter. This resolving power is adequate for the analysis of most metallic substances except those that emit a large number of closely spaced lines; examples are iron and the rare-earth elements. A replica grating of this size can be obtained from the Edmund Scientific Co., Barrington, N.J. 08007. The catalogue number is 50,220.

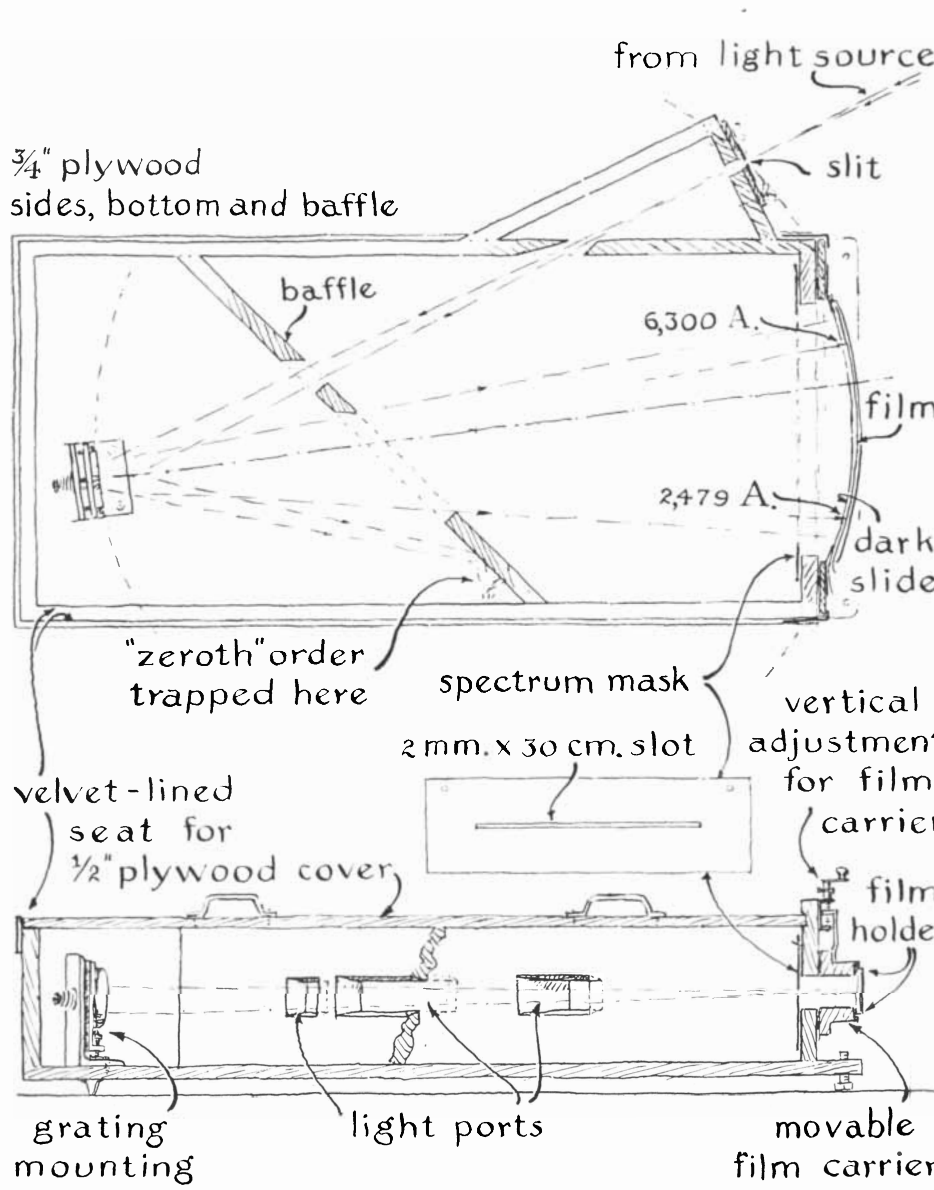
"Begin the construction by drawing on a flat surface a circle with a radius of 53 centimeters. On this 'Rowland circle' locate the exact positions of the slit, grating and camera or film holder as specified in the accompanying illustration [*page 278*]. The outline of the spectrograph housing, also shown in the illustration, should be superposed on the circle. The dimensions of the housing are not critical but construction problems will be minimized if they are followed closely. The light baffle not only prevents scattered light from entering the camera and fogging the film but also

serves as a support for the top of the housing. All interior parts are painted black to minimize unwanted reflections from the various surfaces.

"The camera consists of a lightproof box that encloses a film holder curved to match the circumference of the Rowland circle [*see illustration on page 284*]. The curved members of the box are wooden arcs of slightly smaller radius than the Rowland circle. This difference in radius compensates for the thickness of the film holder and thus ensures that the emulsion of the film follows precisely the curvature of the Rowland circle.

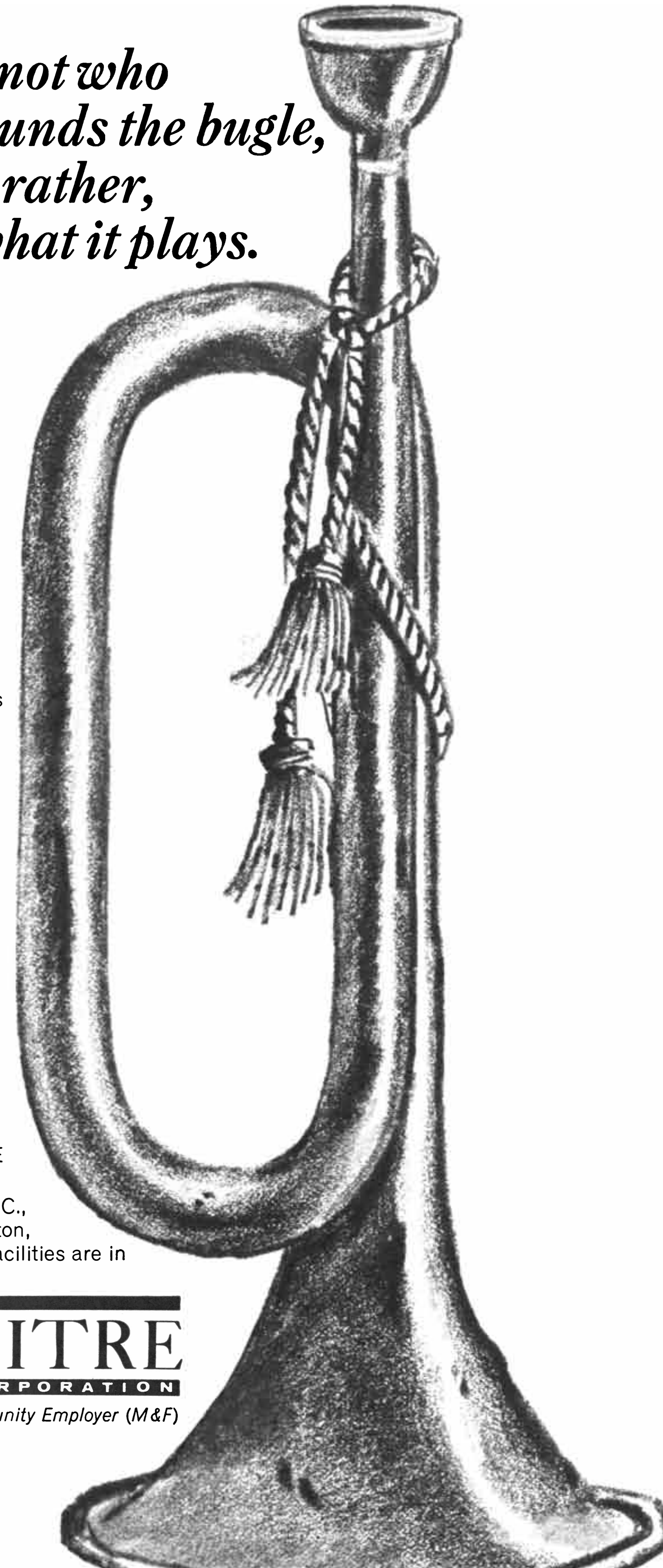
"Each of the wooden arcs is attached to the camera support by wood screws, and additional support is provided by the steel angles. The machine screws needed to attach the film holder are fastened in place with epoxy cement. The several brass strips that constitute the film holder are also assembled with epoxy cement. Coat the surfaces as indicated and mount the assembly on the camera by means of the nuts. When the cement has hardened, the holder will have assumed permanently the shape of the Rowland circle. Do not neglect to install black felt or velvet for blocking light at the indicated points where the removable slides provide access to the film.

"The camera slides up and down on ways. Light is admitted to the film through the thin horizontal slot in the mask of sheet metal. Altering the vertical position of the camera in its ways enables the experimenter to record several spectrograms on a single sheet of 35-millimeter film. An indicator on the racking mechanism marks the position of the film with sufficient accuracy so that successive exposures can be separated by .5 millimeter. An internal shutter, which can consist of a hinged flap of sheet metal, must be installed in order to close the entrance slit through which light is admitted to the spectro-



Plan and elevation views of Epstein's spectrograph

Ask not who sounds the bugle, but, rather, what it plays.



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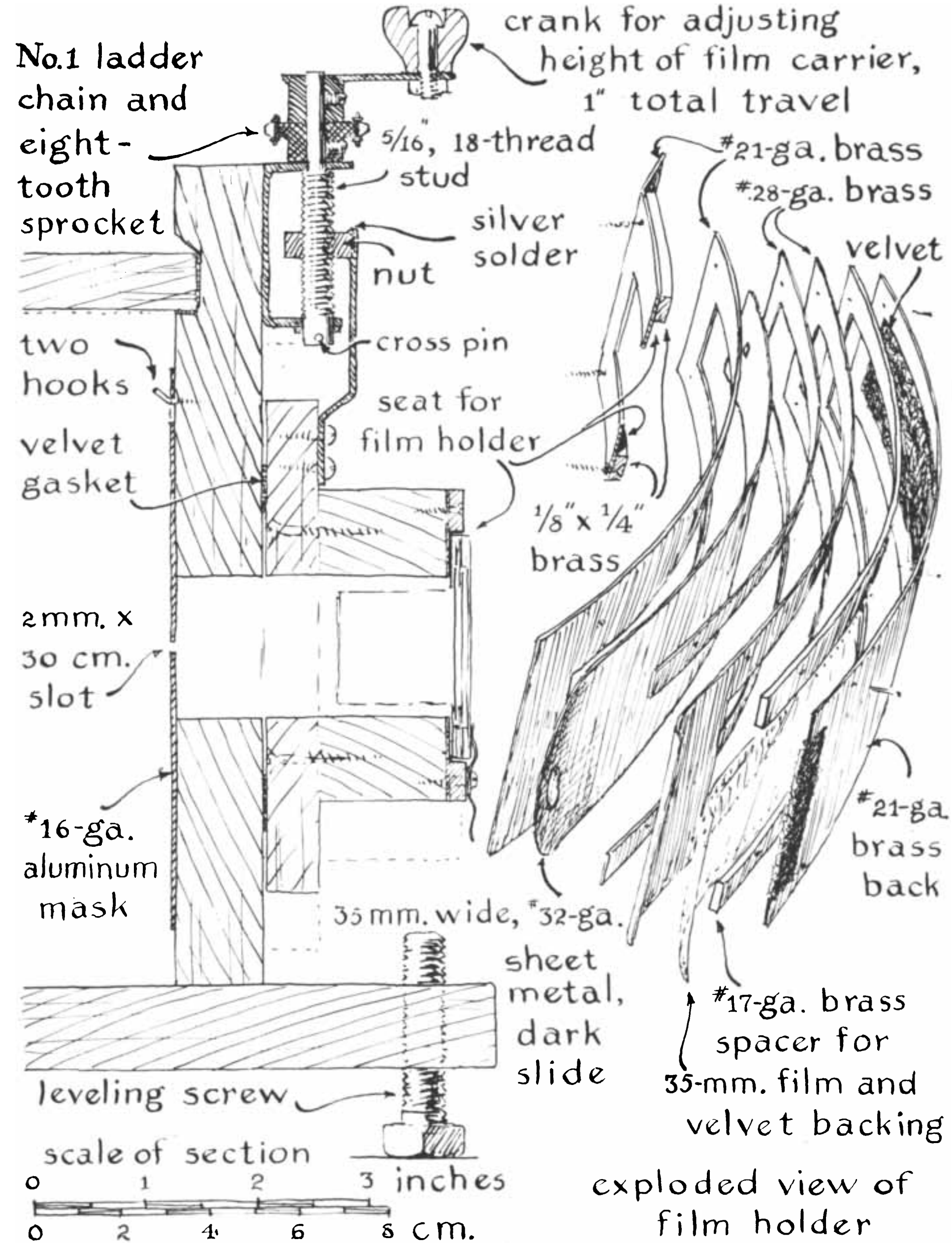


Details of the film holder

graph. The shutter can be operated either electromagnetically or by a mechanical shaft that extends through the side of the housing.

"The slit consists of a pair of safety-razor blades [*see illustration on page 286*]. Two slit assemblies should be made, one with a spacing of about 50 microns for use with intense light sources and another of 150 microns for observing flames. To set the 50-micron spacing loosen the screws that clamp the razor blades, slip a sheet of notepaper between the cutting edges, press the edges snugly against the paper and tighten the screws. Use a stack of three or four sheets for adjusting the wider slit.

"As I have indicated, spectral lines shorter than 4,000 angstroms are of most interest in spectroscopic analysis. They must be photographed because the eye is insensitive to this part of the spectrum. The Eastman Kodak Company manufactures two special emulsions for spectrographic work: Spectrum Analysis No. 1, SA 421–1, and Spectrum Analysis No. 3, Sp 421–1. Both are sensitive down to about 2,200 angstroms. The upper limit of the No. 1 emulsion is about 4,500 angstroms (deep blue); that of No. 3, about 5,300 angstroms (green). Panchromatic film must be used for recording the complete visible spectrum. The special spectrographic emulsions are sold in 100-foot rolls that cost about $12 each. Single rolls can be bought from Spex Industries, Inc., 3880 Park Avenue, Metuchen, N.J. 08841.

"Unless the experimenter insists on achieving the best possible results in the extreme portion of the ultraviolet range, ordinary black-and-white emulsions can be used. The usual precautions should be taken to avoid accidental ex-

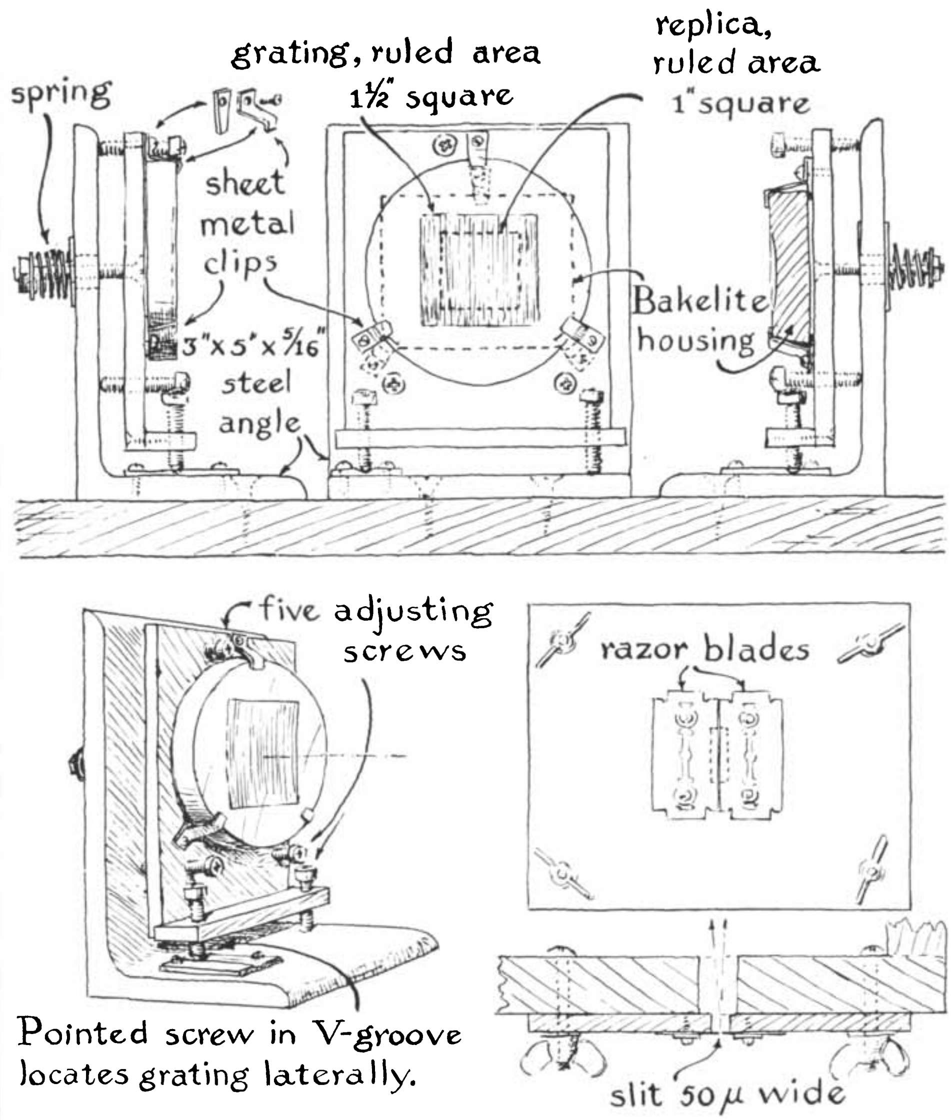
posure when loading the film holder. The films should be developed for high contrast. I use Kodak D-19 developer. The negative is used for analysis. No positive print is required. When making an exposure, pull the opaque slide out just far enough to clear the film aperture of the holder and remember to push it back again before removing the holder from the camera.

"Atoms emit bright-line spectra only when they are excited in the gas or vapor state. At relatively low temperature, however, such as the temperature of an ordinary gas flame, this applies to only a few elements, including potassium, lithium, calcium, barium, strontium and copper.

"Some 25 additional metals can be added to the list by substituting a flame of acetylene and compressed air for natural or manufactured gas. The results of flame excitation can be improved by preparing the specimens in the form of a chloride salt solution. The solution is sprayed into the flame with an atomizer during the exposure.

"The most widely used sources of excitation are electric arcs and sparks. The arc is struck between rods of highly purified graphite specially manufactured for spectrographic work and is sustained by a direct current of about eight amperes. Electrodes of spectrographic grade can be bought from the Ultra Carbon Corporation, Post Office Box 747, Bay City, Mich. 48706. An inexpensive power supply for operation from a 110-volt, 60-cycle power line can be constructed by connecting as a full-wave rectifier four silicon diodes of 10-ampere capacity that are designed for 200-volt operation. These can be bought from most dealers in radio supplies. A resistor must be connected in series with one side of the power line to limit the current. It can consist of a replacement unit of the type used in radiant heaters. A 750-watt unit will do, as will a group of seven 100-watt incandescent lamps connected in parallel.

"The carbon electrodes of the arc must be supported in vertical alignment by a pair of insulated jaws that can be



Arrangement of the grating and the slit

Most engineers are lucky to be in on a handful of space missions during a lifetime.

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moved together for striking the arc and then separated as soon as the carbon rods become hot enough to maintain an arc. A rack-and-pinion mechanism is the preferable means of moving the jaws. Small used arc lamps easily modified for supporting the carbons vertically can be obtained from dealers in theatrical supplies. The arc should be fully enclosed except for an exit window that will allow a beam about an inch in diameter to fall on the slit of the spectrograph. An experimenter must protect his eyes by wearing welder's goggles when the arc is in operation.

"The material to be analyzed is applied to the tip of the lower carbon rod, which is made the cathode. An axial hole half the diameter of the carbon rod can be drilled to a depth of about an eighth of an inch in the tip of the cathode for admitting powdered specimens. A shallow cut by a saw can also be used. Fluid specimens can be applied to the rod by dipping the tip of the cathode into the solution and letting it dry. Highly volatile specimens should be mixed with powdered graphite to retard the rate at which they evaporate in the arc. Some highly refractory specimens that volatilize at a rate too slow for analysis can be mixed with ammonium chloride. Heat decomposes this salt, which then carries the unknown material into the arc.

"To adjust the spectrograph for operation remove the slit from the instrument and substitute a slit about one millimeter wide made by placing two strips of masking tape over the slit aperture of the housing. Cut a strip of white paper 32 centimeters long and 10 centimeters wide. This strip is used as a temporary screen. Bisect it lengthwise with a heavy black line and make two vertical lines to indicate the ends of the spectrum aperture. Tape the strip to the inside of the camera section. Center the horizontal line with respect to the opening. Darken the room and direct a flashlight beam into the slit. Adjust the grating so that the resulting spectrum is centered vertically and positioned at the long-wavelength end of the screen. Remove the paper.

"Place a few large crystals of rock salt on a metal screen above the flame of a gas burner and focus the resulting yellow light on the slit with a magnifying lens. The burner should be about 18 inches from the slit. Tape a piece of translucent wax paper three inches wide across the camera opening so that it covers the 5,893-angstrom point, which is about 2.6 centimeters from the long-wavelength end of the opening. A broad

yellow line will appear on the screen. Adjust the grating until this line occupies the 5,893-angstrom position.

"Remove the paper and install the permanent slit. Load the camera and place it in position on the instrument. Rack the film holder to either the top or the bottom. Charge the bottom electrode with iron filings. Put the arc about 12 inches from the slit, aligned so that the beam transmitted by the slit floods the grating. Make exposures by striking the arc and opening the shutter. The correct exposure is the one that results in the greatest range of line density. It must be determined experimentally.

"The line images may be fuzzy. If so, the instrument should be focused. Set the grating at one of its limits of travel, either toward or away from the film. Then make a series of exposures, advancing the grating in equal increments toward the limit of its travel after each exposure. Keep a written record for correlating the successive positions with the exposures.

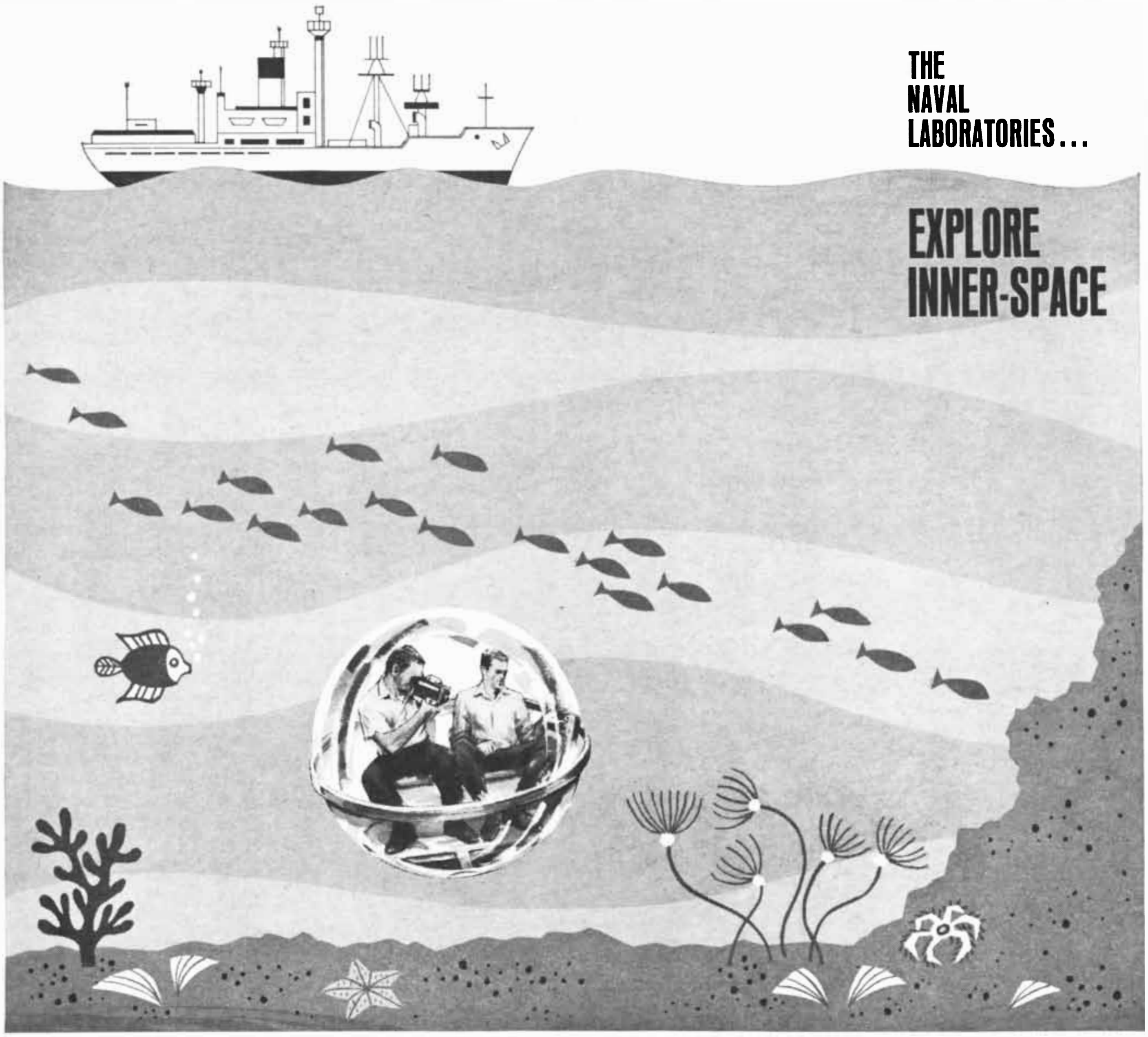
"After developing and examining the film, set the grating at the position that yields the sharpest image. If close examination discloses that each spectral line actually consists of a closely spaced group of fine lines, the slit is not parallel to the rulings of the grating. This can be corrected by rotating the slit in its oversized mounting holes. The instrument is now ready for use.

"Analysis of spectrograms requires the precise measurement of the line positions. The measurements can be made conveniently by projecting an image of the lines on a screen along with that of a scale calibrated in angstroms. A standard 35-millimeter projector can be modified for projecting the spectrogram and scale simultaneously.

"The standard used for calibrating the scale can be a spectrogram of carbon. Strike an arc between a pair of clean spectroscopic carbons and make an exposure. The most prominent features on the resulting spectrogram will be the two cyanogen (CN) bands starting at 3,883 and 3,590 angstroms and the 2,479-angstrom carbon line [*see illustration on page* 277].

"Lay the film on a flat surface and measure the distance between the 2,479-angstrom line and the head of the band beginning at 3,883 angstroms. Assume that it is 88 millimeters. If so, each millimeter represents 16 angstroms ($3{,}883 - 2{,}479/88 = 16$). One hundred angstroms will occupy 100/16, or 6.25, millimeters, and a scale that is 25 centimeters long will span 4,000 angstroms.

"Draw the scale on white cardboard,



The sea has always held a special fascination for man. Eons ago, the waters of the world gave birth to the life from which he evolved. Since he became a land creature, man has increasingly sought to explore the ocean's depths, as well as its surface, seeking to accommodate himself once more to this dark and unknown region of "inner-space". Today science, through such research equipment as the experimental glass sphere developed by U.S. Naval Laboratories, is continuing this rewarding exploration. This unique sphere, fashioned of light-weight glass, may be forerunner of a new breed of relatively inexpensive submersibles. Tests conducted at depths to 20,000 feet indicate that such spheres gain tremendously in strength under deep sea pressure. In implementing the exploration of "inner-space", and a variety of other challenging Navy Programs, the Laboratories need qualified scientists and engineers . . . working in disciplines covering the entire spectrum from physics to mathematics, from mechanical to electronic engineering, from chemistry to metallurgy and many other special disciplines.

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divide it into 40 increments of 100 angstroms each, photograph the drawing and make a positive transparency with an enlarger. The final image should be precisely 25 centimeters long. Draw an auxiliary scale 12.5 centimeters long and divide it into 20 equal increments. The ratio of this scale to the one previously drawn is 20:1; when the scale previously drawn is magnified 20 diameters by projection, the distance between adjacent graduations is 12.5 centimeters and spans 100 angstroms. Line positions can be measured to within one angstrom by placing the auxiliary scale between a pair of projected graduations.

"To determine positions of the lines emitted by an unknown chemical element, make a spectrogram of carbon and on the same film a spectrogram of the unknown element. Insert the film in its compartment in the holder and move the spectrogram with respect to the scale until the 3,883-angstrom point of the scale coincides in position with the 3,883-angstrom cyanogen band head. The distance between the projector and the screen must of course be adjusted for a magnification of 20 diameters.

"Using the auxiliary scale at the screen, measure in angstroms the spectral positions of the lines you believe to be those emitted by the unknown element. Always look for the most prominent lines of an element when trying to establish its presence in the sample. Extensive tables of wavelengths can be found in *The Handbook of Chemistry and Physics*. At least two lines of an element must be detected before it can be considered as being definitely present. Not even the roughest estimate of its presence can be made, however, unless the spectrogram can be compared with one of a similar type of sample material containing a known amount of the element in question.

"Imperfections in a grating can produce 'ghost,' or spurious, lines. Ghosts are easily spotted. They always occur in telltale pairs spaced symmetrically on opposite sides of the parent, or true, line, which is usually of high intensity. Ignore the ghosts.

"The spectrograph can be used for the analysis of many different types of material such as glasses, soils, ceramic materials and ashed substances of all kinds. It is particularly applicable for detecting fractions in concentrations of 1 percent to .0001 percent and even less in some cases. Amateur prospectors, for example, can readily check rocks for metals in amounts far below those required for ordinary chemical or blowpipe analysis."

BOOKS

Does the American jury system work?

by Mark DeWolfe Howe

THE AMERICAN JURY, by Harry Kalven, Jr., and Hans Zeisel, with the collaboration of Thomas Callahan and Philip Ennis. Little, Brown and Company ($15).

For more than a decade the University of Chicago Law School has been engaged in a nationwide study of the jury system. This ambitious project is a novel one as well, because it brings lawyers and social scientists together in the search for truth and understanding. As a result we are beginning to hear emancipated law professors speak casually of the directionality of the data, the differential credibility judgments of juries, viable clues from reason assessment and *Gestalt* evaluation by judges. Sociologists, for their part, no longer trip over *de minimis non curat lex* (or *praetor*) and *autrefois acquit,* writs of error and *certiorari,* the M'Naghten rule, or burdens of proof and burdens of persuasion. The two worlds of discourse have become one. This fruit of the union of jurisprudence and social science has inevitably been christened "jurimetrics."

The jury project is distinguished also as a data-gathering enterprise. It has conducted "field research" on a scale in keeping with its substantial funding by the Ford Foundation. Indeed, the dimensions of this firstborn child of Chicago and Ford are grand enough to merit status as a subdiscipline known by the foreordained nickname of "jurymetrics."

The present volume is one of a series of studies that is to issue from this inquiry into the American jury. It is therefore unfortunate that the book should bear that title. In actuality it seeks to do no more than consider the functioning of the trial jury in criminal prosecutions; the authors promise another book about trial by jury in civil cases. The deception would be unimportant if it did not imply that the distinctions between the role of the jury in criminal cases and in civil cases are of negligible significance. The senior authors Harry Kalven, Jr., and Hans Zeisel are, as lawyers, thoroughly aware of the differences in the lines of history, power and policy that have shaped the jury's function in criminal trials and in civil litigation. I am not so comfortably assured, however, that those who come to jurimetrics from outside the law will share the lawyer's understanding of the reasons why "the American jury" must be studied as two largely separate and independent institutions.

In designing their study of the criminal jury the authors made a decision of crucial importance, a decision they persuasively explain and justify. They sought, as their primary data, specially prepared reports by 600 judges who had participated with the juries being analyzed in the trial of 3,576 criminal cases around the country. The study therefore rests on "just three items: the actual verdict of the jury, the hypothetical decision of the judge, and the judge's explanation of the disagreement when his decision differed from that of the jury." The authors are quick to acknowledge the limitations of their method. They are able to argue that by comparison with other methods it "emerges as the most rigorous practicable approach" to the grand experiment of having each case "tried by a jury and also by a judge, thus obtaining matched verdicts for study." They present numerous tables, furthermore, to show that their 3,576 cases constitute a valid sample of the 60,000 criminal cases tried annually to American juries.

I am neither competent nor inclined to question the authors' confidence that they have, within the presuppositions that controlled their inquiry, succeeded in the behavioral aspects of their study. My own confidence in the work rests on the somewhat deflationary fact that virtually all the conclusions the authors have reached by their elaborate statistical and sociological procedures seem absurdly obvious.

Surely it required no very complex machinery of investigation, research and analysis to conclude that a jury's verdict in close cases is likely to be affected by its feeling that the defendant is or is not a sympathetic and attractive person. Even the most plodding interpreter of human nature might have concluded, without the benefit of Ford financing, that the jury is more likely to come back to the judge with questions in the difficult cases than in the easy ones. Perhaps he would not have known that the incidence of inquiry is about twice as high in the difficult cases as it is in the others. It comes as no exciting or momentous shock to learn that fact through the probing inquiries of social science.

The authors recognize the possibility that their enterprise has done little more than confirm the obvious. They state that the outcome of the inquiry, phrased in its "least exciting form," asserts that "all disagreement between judge and jury arises because of disparity of counsel, facts that only the judge knew, jury sentiments about the defendant, jury sentiments about the law, and evidentiary factors, operating alone or in combination with each other." The flaccid corollary to these banal findings declares that "the judge is less likely to be influenced by these factors than is the jury."

No one wants to be inhospitable to cooperative ventures in research. Yet one cannot disregard the overwhelming improbability that many important or startling conclusions could be drawn about the forces that lead 12 jurors—who must reach a unanimous verdict—to see things differently from a single judge.

This is not to discount instances in which the intelligent and imaginative industry that animated this study has uncovered data casting fresh light on the psychology of the American juror. One is both surprised and reassured to be told that jurors show "a modest tendency" to treat favorably those defendants who have been made the victims of one or another form of police skulduggery or brutality. They also have a wholesome, if somewhat lawless, inclination to look charitably on those defendants who have done injury to persons whose carelessness, violence or aggression induced the defendant's criminal act. Perhaps the tendency of jurors to allow the instinct of self-help to play a larger part in the control of social behavior than government has officially assigned it reflects a streak of anarchy in the American spirit. In any case, the existence of the tendency is frequently apparent in the data.

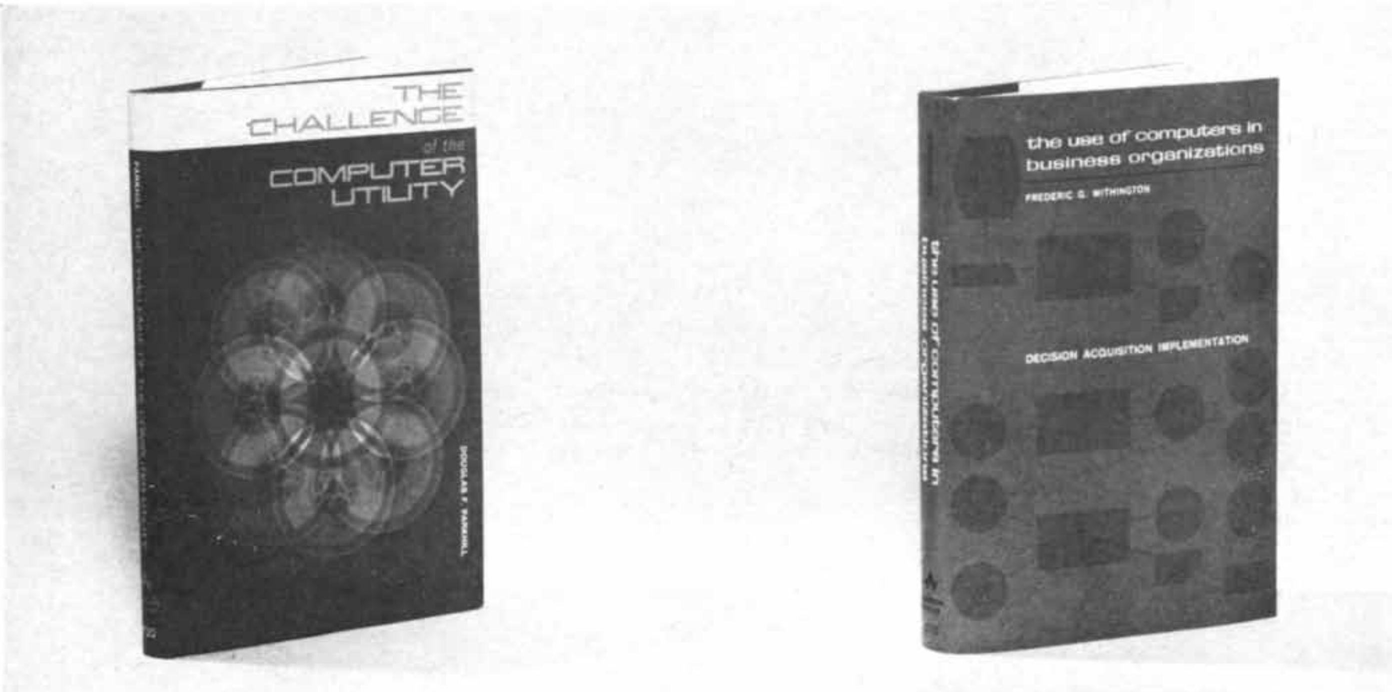
This phase of the findings compels consideration of a large question concerning the inexplicit premises of the inquiry. The question I have in mind has two aspects. The first concerns the extent to which the entire inquiry rests on the supposition that the new science of jurimetrics may ignore legal history. The second aspect, not unrelated to the first, concerns the role played in this inquiry by the familiar dichotomy of "the law" and "the facts." The authors proceed on the apparent supposition that criminal law is a body of principle exclusively committed to the custody of judges—so exclusively that jurors, although they may have the power to take the law into their own hands and thus alter it, are not legally entitled to do so. They tell us that their study "is a contribution to what has often been called realist jurisprudence." I would suggest that a jurisprudence as indifferent as theirs is to the facts of legal history can scarcely claim to be realistic. Let me try to sharpen this statement by specific illustration.

A jury's verdict of acquittal is, of course, conclusive and final; it cannot be appealed by the prosecution. Like other lawyers, the authors find reassurance in fixing a tag on the principle; they label it the constitutional rule against double jeopardy. To stop there, however, is to betray indifference to the significance of some important history. The finality of an acquittal is the remnant of a tradition that sanctified, as it were, all jury verdicts in criminal cases. That tradition, if taken seriously, legitimates the power of jurors to make themselves the partners of judges in making the law. Legitimating the jury in this function jeopardizes the clarity bestowed on legal analysis by the drawing of a sharp line between questions of fact and questions of law. It also threatens the scheme for administering justice, renewed in every charge to the jury, that assigns questions of fact to the jury and reserves questions of law to the judge.

In fixing the structure of presuppositions underlying the present study, the authors were compelled to make a choice between the clarities that accompany analytic orthodoxy and the confusions that make up the reality of our inheritance. Being, in this enterprise, jurimetricists and not legal historians, they chose the molds of analytic rather than historical jurisprudence for the ordering of their materials. Perhaps the choice was wise. The choice entailed a greater repudiation of realism, however, than the authors seem to realize. It compelled them to disregard the high probability that jurors—and even some hardheaded and unphilosophic judges—may not discern the sharp line between the facts and the law.

As a matter of fact, that line appears somewhat blurred in the jury-project data concerning the attitude of judges and jurors toward a familiar qualification of the right of self-defense. A person whose life is threatened by another's violence has the duty to retreat before he shoots his aggressor. The authors build their analysis on this heading from the orthodox assumption that there is a clear rule of law in each jurisdiction defining with more or less liberality or severity the scope of this duty to retreat. In other words, it is assumed that the law provides the standard with which to measure this dimension of the defendant's right when threatened to stand his ground and meet force with equivalent force. Not surprisingly, the data reveal a tendency among juries to disregard the "rule of law" that prevails locally. Instead, juries tend to create for each case a standard that determines criminality on an essentially *ad hoc* basis.

The present study finds that cases of this kind occasion frequent disagreement between judges and juries. From the presentation and discussion of these cases one would not suspect that the authors may be mistaken in their assumption that the prevailing jurisprudence of self-defense provides a rule of law for the proper resolution of such controversies. Yet I believe judges as well as juries proceed on the assumption that the standard of criminality—the rule of law—is to be made by the jury's assessment of the measure of restraint the defendant could have been expected to show in the moment of his confrontation with his victim's threat of violence. To make such a large concession to whim and thereby accentuate the unpredictability of litigation may be unfortunate and unwise. It seems more honest, nonetheless, to recognize that few judges and fewer jurors are likely to hold sacrosanct the jurist's prescription for order. They are likelier,



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I believe, to let traditions the jurist has forgotten survive as operative fact. In other words, they are disposed to assume that jurors may be participants in the making of rules of law.

If one is willing to see some of the practices of American juries as habits and customs persisting from a forgotten history rather than as lawless violations of the axioms of jurisprudence, he may interpret the data on another heading differently from Kalven and Zeisel. As the study shows, juries commonly tend to disregard a fundamental axiom of our jurisprudence that the only parties to litigation in the criminal law are the state and the defendant. Thanks to this sloppy indifference, many jurors allow the contributory negligence or the viciousness of the victim of the crime to enter into their weighing of the culpability of the defendant. In other words, the jurors confound the clear distinction between the civil and the criminal law and look on the action charged to the defendant as a tort rather than a crime. "The cases," we are told, "show a bootlegging of tort concepts of contributory negligence and assumption of risk into the criminal law." The authors do seem willing to recognize that the juries in these cases may be following in the footsteps of unphilosophic and unscientific ancestors. That recognition should, I believe, have played a larger part in all aspects of this investigation. A jurisprudence is realistic only if it takes into account the hold that the past, rightly or wrongly, has over the present. The past is not merely the hunting ground of antiquarians; it has live relevance to the jurimetricist's interpretation of the human behavior he observes today.

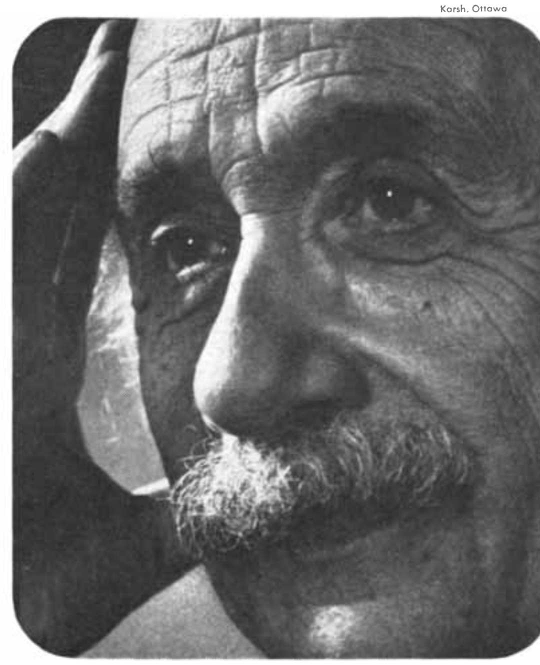
The Chicago study is surely destined for a long period of time to be the starting place for all public discussion of the proper role of the jury in the administration of justice. Many will ask the same question James Fenimore Cooper asked more than a century ago: In a society that has been foolish enough to establish an elective judiciary and wise enough to make judicial tenure subject to good behavior, does a jury serve any more useful purpose than that of a symbol of freedom? On Patriot's Day we celebrate the fortitude of the juries that set William Penn and John Peter Zenger free. On what days shall we celebrate the courage of those solid yeomen who, in our own day, saw fit to let the killers of Medgar Evers, Mrs. Viola Liuzzo and Jonathan Daniels go free? There are surely occasions on which one is tempted to suggest that the time has come to amend our constitutions so as to allow the abolition of the jury even in criminal cases. Indeed, on one ground or another, trial by jury is denied, waived or avoided in 75 per cent of the 250,000 criminal trials conducted annually in this country. The suggestion that it be abolished, I feel sure, is worth serious consideration.

Before that happens, however, I hope that someone will undertake a study no less extensive than the Chicago-Ford jury project to determine whether or not our judges are to be trusted with the power that would be theirs were they to go it alone. I confess *The American Jury* seems infected by an excessive respect for the vision, wisdom and integrity of American judges. I have too often heard practicing lawyers from our large cities insist that the one reason—and that a compelling one—for preserving jury trial is that it is our best safeguard against the corruption of judges.

The authors were right to exclude from this particular inquiry a search for data concerning the quality and capacity of judges. At some phase of the inquiry, however, I hope there will be clear recognition that trial by jury is always, in fact, trial by judge and jury. Until we know more than we do of the conduct and performance of our trial-court judges we shall not be able wisely to evaluate the condition of trial by jury in the U.S.

Short Reviews

The Arctic Frontier, edited by R. St. J. MacDonald. University of Toronto Press ($7.50). Antarctica, edited by Trevor Hatherton. Frederick A. Praeger ($18.50). "This gloomy region," a 19th-century traveler wrote about the Arctic, "where the year is divided into one day and one night, lies entirely outside the stream of history." The gloom, the long days and nights remain unchanged, but the polar regions of the world—antarctic as well as arctic—can in our day scarcely be said to play no part in world affairs. MacDonald's book is primarily about the Canadian North, but its key theme (well expressed by one of the contributors, the geographer Michael Marsden) is that the most essential quality of the Arctic "is not cold, or gold, or polar bears, but a central position in the world community." Of this community, the major members, besides Canada, are the U.S.S.R., the U.S., Denmark (Greenland), Iceland and Norway. In that region they are bound together not only by geography but also by common economic, political and scientific in-



terests and by the hostility of the two superpowers. One of the refreshing things about the MacDonald volume is that only one essay is devoted to the strategic significance of the Canadian Arctic; the other contributions consider such topics as the administration of northern peoples in the U.S.S.R., Canada and Alaska, the fate of the Eskimos as "pawns of history," the questions of sovereignty in the north, the international implications of arctic exploitation. Of unusual interest are the descriptions of the many tribes and nations living in the north. There are no fewer than 19 of them, including the Lapps, the Nentsy, the Nganasanis, the Komi, the Yakuts, the Aleuts and the Chukchi. Some of these groups are tiny (at the last census there were fewer than 400 Aleuts); some are large (there are more than a quarter of a million Komi). The book offers a balanced presentation, neither exaggerating the importance of the Arctic nor deflating it to fit the shifting winds of military strategy.

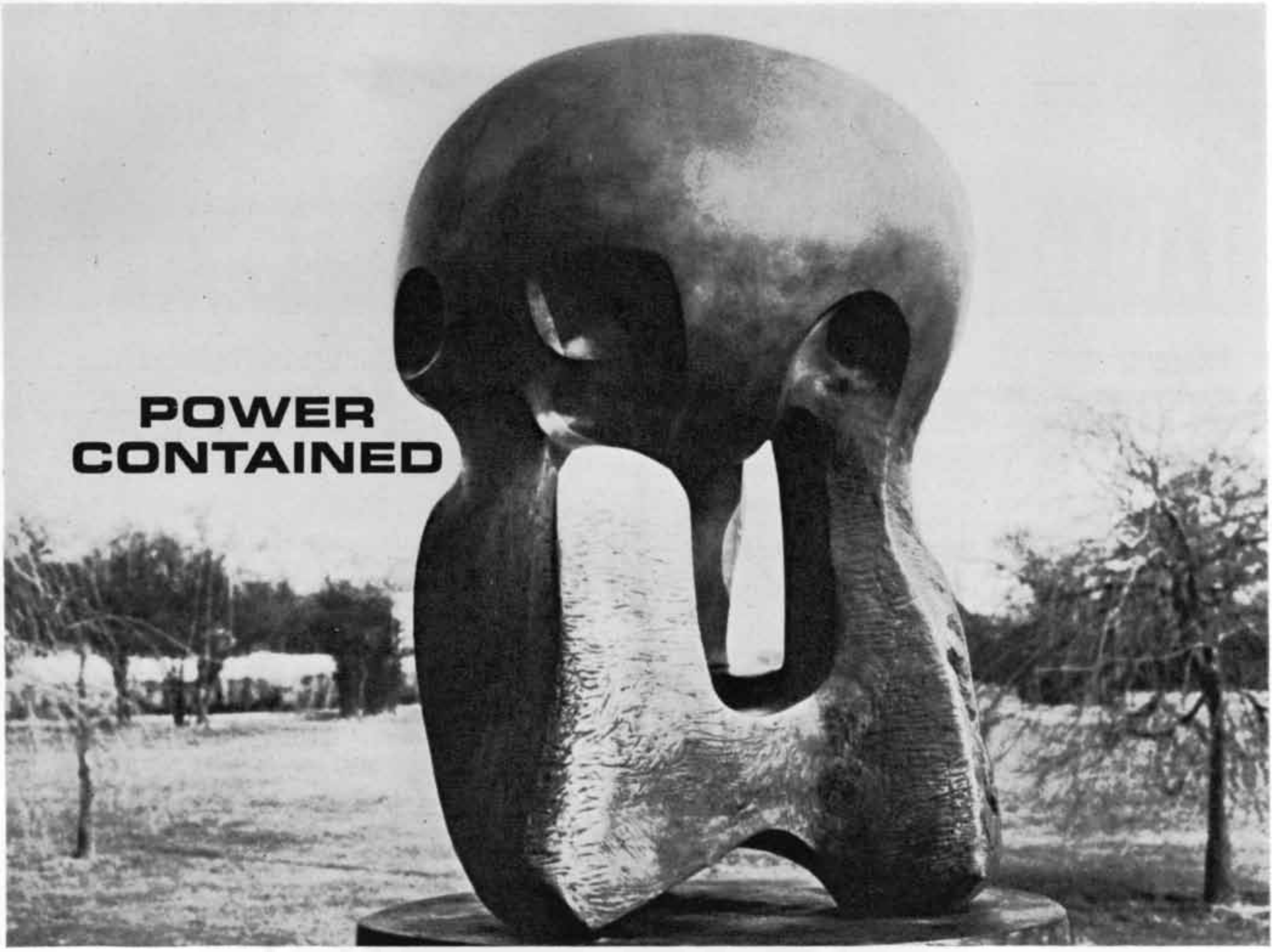
Hatherton's book, published with the cooperation of the New Zealand Antarctic Society, supersedes a mid-century survey: *The Antarctic Today,* published in 1952. Since then, of course, various nations that have lodged themselves in the Antarctic have greatly enlarged knowledge of the region. They have mapped some of the land, probed for mineral resources, observed its ocean, recorded its birds and mammals, measured its ice shelves and ice sheets, examined its geology, developed antarctic meteorology and have learned how to live in the Antarctic and to move about and communicate there. The chapter that describes this last group of techniques is full of interesting details. The Russians have built themselves a tractor, the Kharkovchanka, that is powered by a 12-cylinder engine, has a cruising speed of eight kilometers per hour, weighs 33.5 tons and has a workroom, radio room, kitchen, toilet, entrance porch and sleeping berths for eight. One of the new ways to build habitations is exemplified by the Byrd Station of the U.S., which sits in a deep trench so that only the curved roof protrudes slightly above the level of the snow. It stands up against the hurricane-force winds much better than aboveground structures but it has its own problems, one of the main ones being the danger of fire. Warm clothing remains a problem to this day. The Eskimo solved it beautifully with a tent-shaped garment, made of warm fur and tied at the neck, that trapped body-heated air and kept him warm. Opening the garment at the neck allowed the warm air to escape and the ventilation could be further increased by opening drawstrings at the bottom of the garment and at the ends of the sleeves. This worked because the Eskimo wore no other clothes under his furs. When condensation produces moisture inside his tent suit, the Eskimo is not bothered: the frost forms at the base of the hairs, and the furs are worn with the hair next to the skin. When the Eskimo goes back to his igloo, he simply turns the garment inside out and shakes off the ice. None of the clothes we have designed meet the difficulties of extremely low temperatures anywhere nearly so well, and for hygienic reasons we use underclothes and other garments that, if they are permeable, have to be worn in so many layers as to impede motion and, if they are nonpermeable, prevent essential ventilation. The shoe problem, however, has been solved by the American "thermal" boot. This footgear incorporates a layer of insulation, coated on both the outside and the inside with impermeable rubber. The sweat of the foot cannot escape through the vapor barrier that arises; therefore the feet become wet. The insulation within the boot itself remains dry and effectively conserves the body heat, so that the foot and the sweat remain warm. Only one pair of socks is used, and they are changed and washed every night. A certain amount of psychological adjustment is said to be necessary to accustom oneself to the sensation of walking about with wet feet, but once one realizes that although one's feet are wet they are warm there is no great difficulty. These boots are effective both in dry cold down to 60 or 70 degrees below zero Fahrenheit and in wet cold and slush. Fridtjof Nansen and Robert E. Peary, as the author of this chapter observes, could scarcely have imagined such bliss as they sledged over slushy summer sea ice.

A Selection of Problems in the Theory of Numbers, by W. Sierpiński. Pergamon Press ($4.50). Excursions in Number Theory, by C. Stanley Ogilvy and John T. Anderson. Oxford University Press ($5). The largest known prime number has 1,332 digits; it is the number $2^{4423}-1$, which, with the help of a computer, was verified as a prime in 1961. (It may be that a larger prime has been verified since Sierpiński's book was written a couple of years ago.) At the beginning of 1951 the largest known prime was $2^{127}-1$, which had

already been proved to be a prime in 1876. The six-millionth successive prime after 2 is 104,395,301. A computer is promised—it may already be in existence—that will contain in its memory 500 million consecutive primes. Sierpiński's book is packed with information about these simple yet endlessly mysterious building blocks of arithmetic. It is about evenly divided in its discussion between what we know about prime numbers and what we do not know. One of its chapters describes 100 elementary but difficult problems in arithmetic, which are of two kinds. For one kind we know how to obtain the complete solution but are not in a position to perform all the necessary computations because of their length, even with the assistance of the most advanced computers. For the other kind no method is known that could lead to a solution, even after the most laborious calculations imaginable. An example of a problem of the first kind is to find all the natural divisors of $2^{101} - 1$. To obtain these divisors one would have to divide the number successively by the numbers 1, 2, 3... up to $2^{101} - 1$ and ascertain which of these divide the number without remainder. This would require computations beyond our present powers. It is curious, as Sierpiński says, that, leaving aside the problem of proving that there exist other divisors of our number (which in itself would not be easy), we do not even know any of them. A problem of the second kind is: Does there exist an even number larger than 2 that is not the sum of two prime numbers? The conjecture that the answer to this question is no was made by C. Goldbach in 1742, but it remains a conjecture. Does the digit 1 occur infinitely many times in the decimal expansion of the number $\sqrt{2}$? Does not the sequence of nine digits 123456789 directly following one another occur at least once in the decimal expansion of pi? Are there infinitely many prime numbers whose digits are all 1? (Only a few primes whose digits are all 1 are known, for example 11 and 11,111,111,111,111,111,111,111, or $10^{23} - 1$.) These are questions to which the sphinx may have an answer, but no mathematician.

Ogilvy and Anderson's book also considers primes, but it includes chapters on number patterns, congruence arithmetic, irrational numbers, Diophantine equations, calculating prodigies, continued fractions, Fibonacci numbers. A large part of the material is fresh, which is to say that it is not part of the trite fare of other popularizations. The problems are well described

GREAT MOMENTS AT CHICAGO



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and are made meaningful, and the proofs and solutions are rendered with sureness, simplicity and clarity. Both books will appeal to anyone interested in mathematics; neither requires more than elementary training to follow the reasoning. They are examples of popularization of the highest order.

MASTERY OF THE AIR, by Sir Graham Sutton. Basic Books, Inc. ($4.95). Some years ago Sir Graham published as a Penguin paperback *The Science of Flight,* which was the clearest and best exposition of its kind. The present volume follows the same lines. Although much of the text has been rewritten, there are more historical detail, new sections dealing with supersonic transport aircraft and artificial satellites and an appendix on the pioneer work of F. W. Lanchester in fluid mechanics and operational research. This is by far the ablest exposition of practical and theoretical aerodynamics addressed to the ordinary intelligent reader. Very little mathematics is used and very little is needed; Sutton has such a masterful grasp of the subject that he can present it in vivid, concrete, understandable terms. Whether he is describing turbulence and drag, the pressure on an airfoil, the function of the propeller, Bernoulli's paradoxical theorem (as velocity increases, pressure decreases), aircraft stability, the Prandtl-Meyer expansion, conformal transformation or whatnot, he instructs the reader and uses just the right analogies to light up his mind. Highly recommended.

BERNOULLI 1713, BAYES 1763, LAPLACE 1813, edited by Jerzy Neyman and Lucien M. LeCam. Springer-Verlag ($9). Proceedings of a research seminar held at the University of California at Berkeley in 1963 marking the 250th anniversary of Jacob Bernoulli's *Ars Conjectandi,* a landmark in probability theory. The volume includes a statement and proof of Bernoulli's famous law of large numbers, Thomas Bayes's "Essay towards Solving a Problem in Doctrine of Chance" (a paper on inverse probability that raised controversies and questions not resolved to the present day) and Pierre Simon de Laplace's "Essai philosophique sur les probabilités." The papers are on statistical topics with one exception: F. N. David's biographical essay on Laplace.

MEMORY: A CONTRIBUTION TO EXPERIMENTAL PSYCHOLOGY, by Hermann Ebbinghaus. Translated by Henry A. Ruger and Clara E. Bussenius, with a new introduction by Ernest R. Hilgard. Dover Publications, Inc. ($1.50). A reprint of the translation of the psychological classic of 1885 that extended the then new experimental psychology beyond the study of sensation and perception to the measurement of learning and memory. Hilgard's wise historical introduction shows clearly how Ebbinghaus, fitting in with the times, brought psychology forward, how far he advanced and corrected the conventions of his day, and how modern he still remains in at least four of his innovations.

PROCEEDINGS OF THE SYMPOSIUM ON CONGESTION THEORY, edited by Walter L. Smith and William E. Wilkinson. The University of North Carolina Press ($14). Man's lot in modern industrial societies is to have to wait—on the road in traffic jams, in the hospital clinic, at the airport, at the bus stop and so on. This volume is the record of a symposium held at Chapel Hill concerned with the mathematics of waiting and queuing.

FLORA OF JAPAN, by Jisaburo Ohwi. Smithsonian Institution ($25). This very large (1,067 pages), double-column, fine-print volume is a much revised and extended translation by the author of two of his books: *Flora of Japan* (1953) and *Flora of Japan—Pteridophyta* (1957). It represents more than 30 years of study and is a major source for botanists, horticulturists and agriculturists. A few plates and figures.

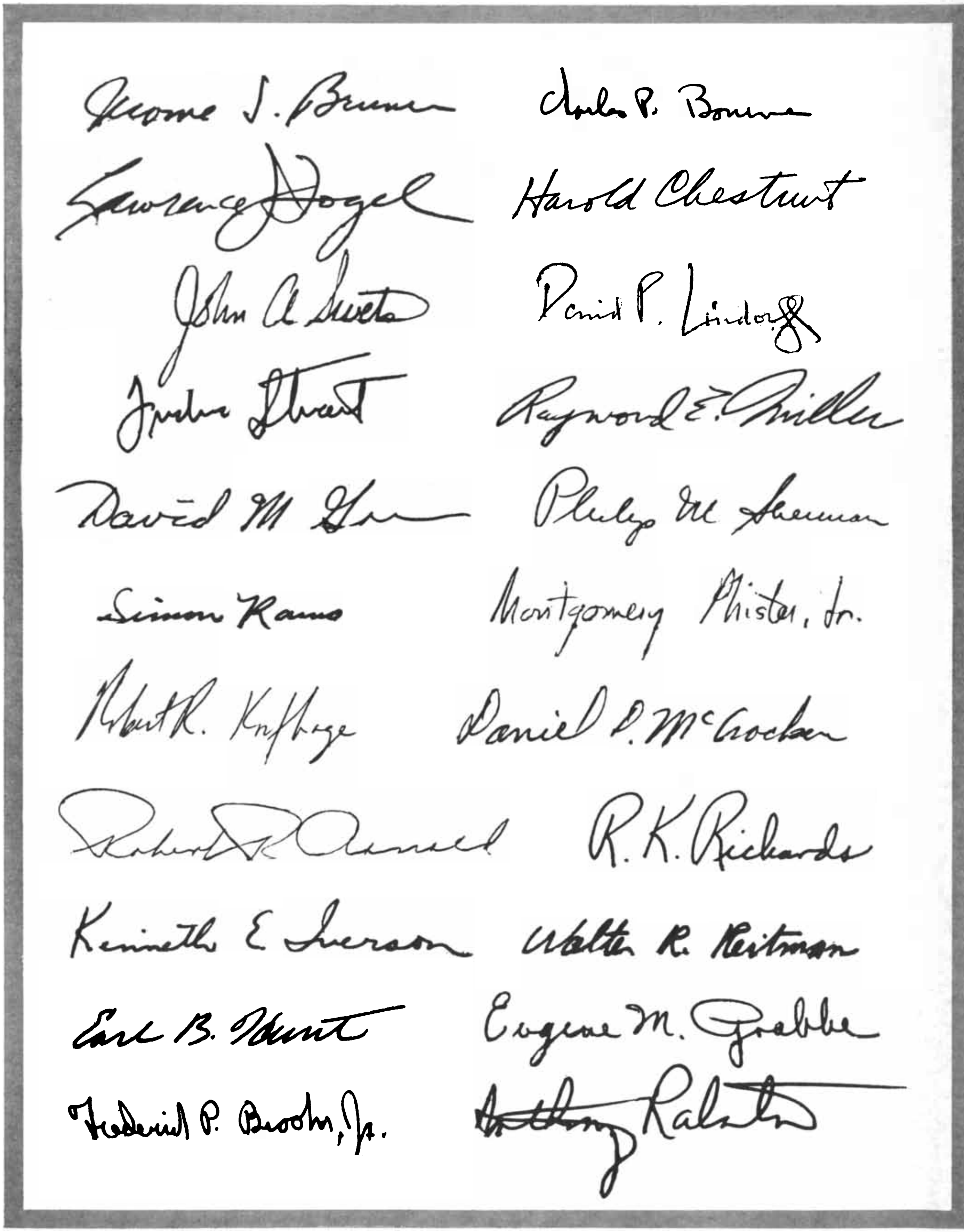
Notes

INTRODUCTION TO SPACE SCIENCE, by the staff of the Goddard Space Flight Center, edited by Wilmot N. Hess. Gordon and Breach, Science Publishers ($29.75). Articles on research opened up by data made available by artificial satellites, concerned with such topics as the earth's magnetic field, atmosphere and radiation belts, the interplanetary medium, cosmic chemistry and cosmic rays, the structure of the planets, extragalactic radio sources.

SCIENCE AND HUMAN VALUES, by J. Bronowski. Harper & Row, Publishers ($3). A revised and enlarged edition of a much admired, often quoted essay, including a new dialogue, "The Abacus and the Rose," originally broadcast by the B.B.C. in 1962, that discusses the theme that "science is as integral a part of the culture of our age as the arts are."

question:

WHAT DO ALL THESE MEN HAVE IN COMMON?



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AUTOMATIC PROCESSING OF NATURAL AND FORMAL LANGUAGES. A. G. Oet-

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