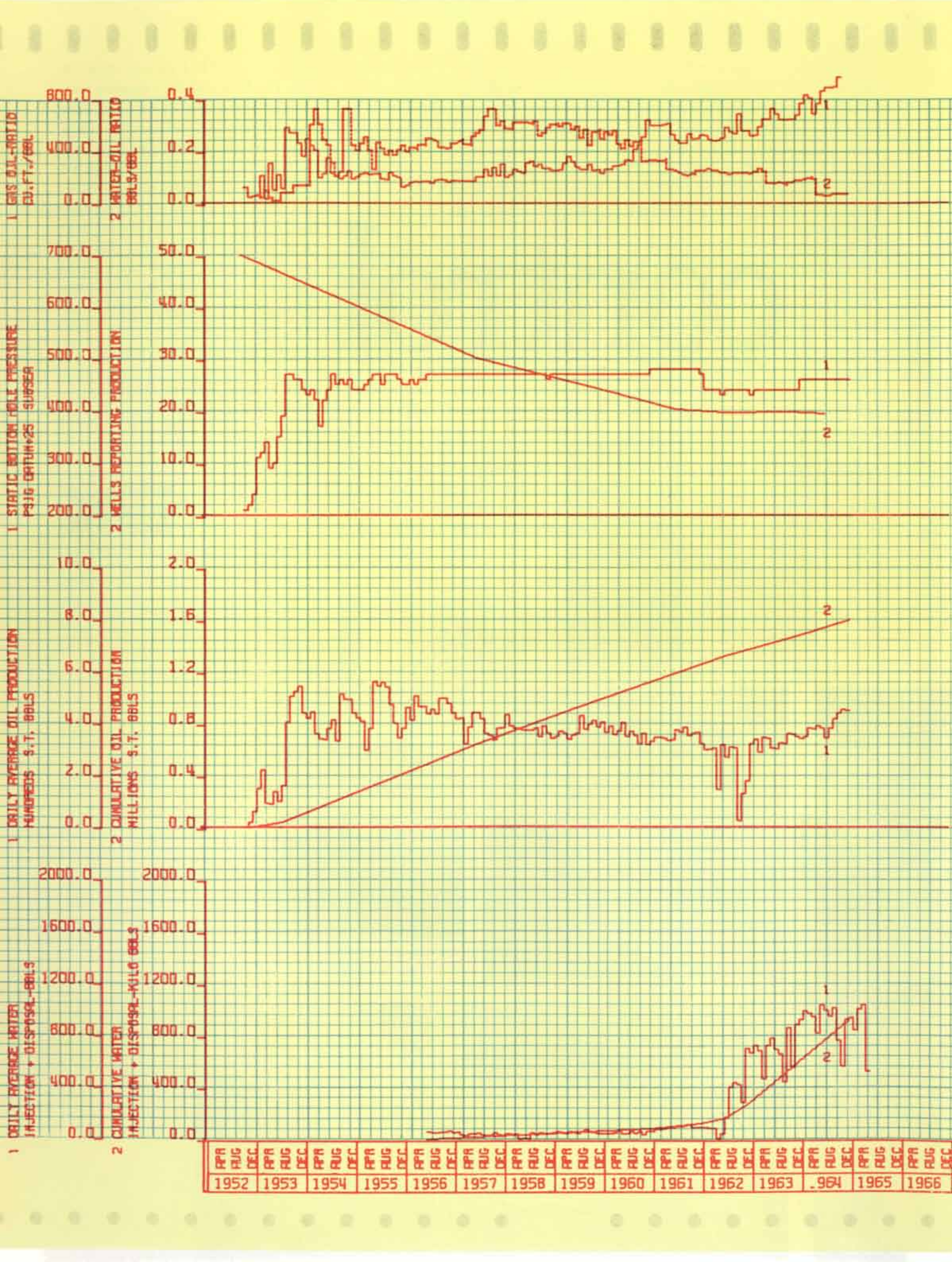

1 GAS OIL-RATIO CU.FT./BBL
2 WATER-OIL RATIO BBLS/BBL
1 STATIC BOTTOM HOLE PRESSURE PSIG DATUM+25 SUBSEA
2 WELLS REPORTING PRODUCTION
1 DAILY AVERAGE OIL PRODUCTION HUNDREDS S.T. BBLS
2 CUMULATIVE OIL PRODUCTION MILLIONS S.T. BBLS
1 DAILY AVERAGE WATER INJECTION + DISPOSAL-BBLS
2 CUMULATIVE WATER INJECTION + DISPOSAL-KILO BBLS
1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 .964 1965 1966

# 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.

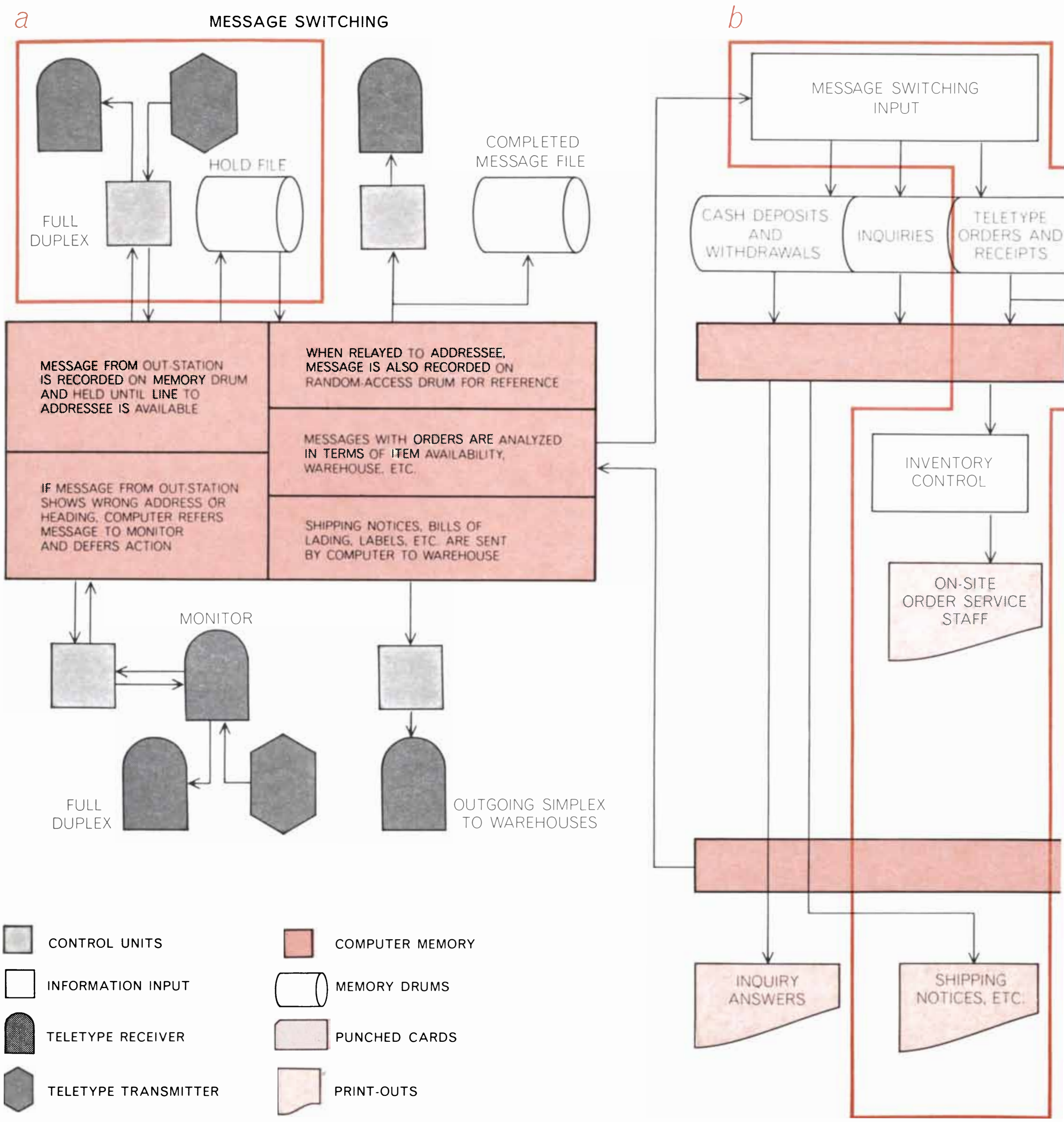
It is startling to recall that this was the situation barely a decade ago. Today tens of thousands of digital computers are employed in business and government in the U.S. By virtue of their flexibility and great improvements in their speed, capacity and reliability, they have been able to take on a 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.

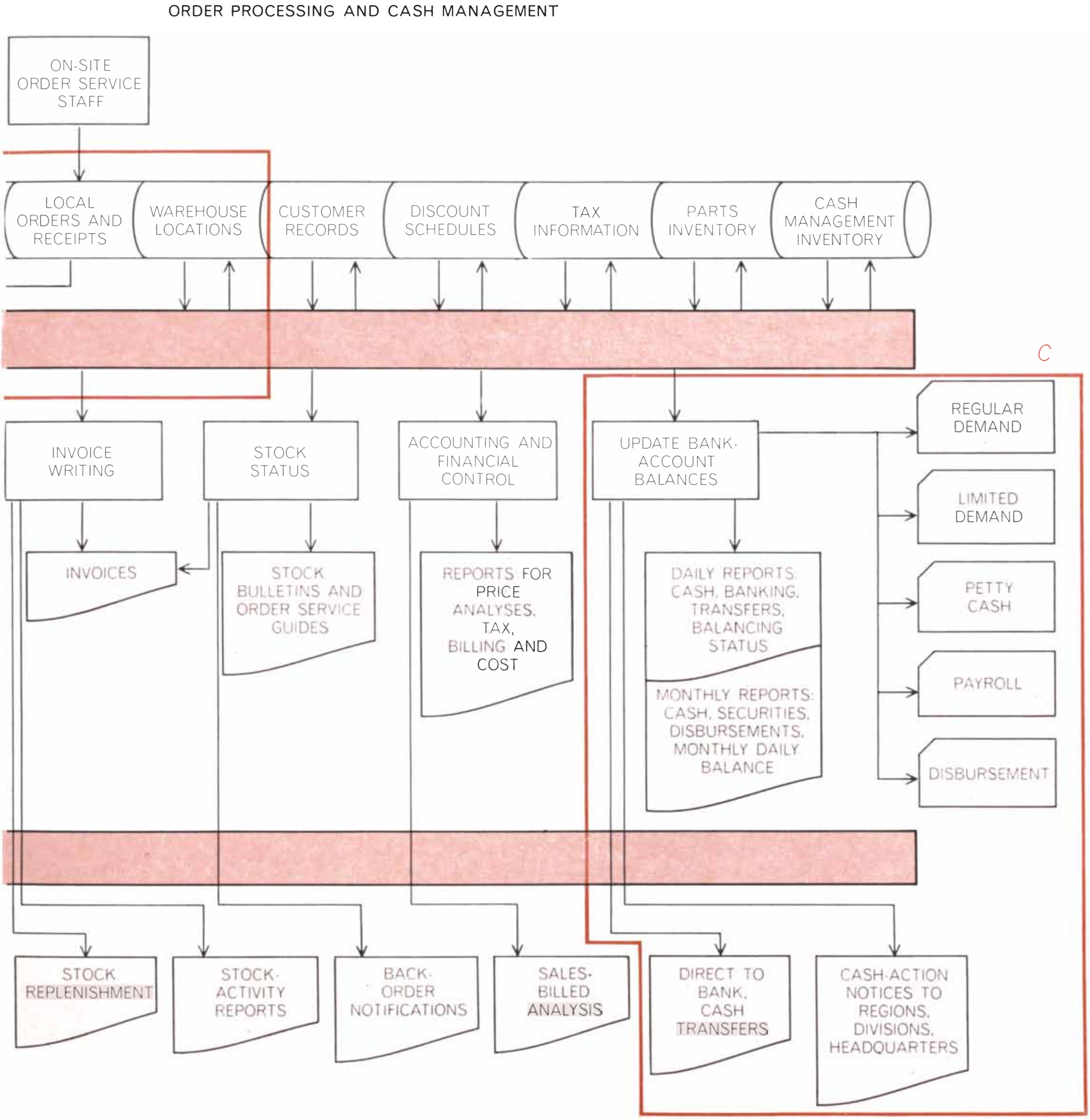
The programmed unit of specialization in a computer system is called a routine. It is a set of instructions for performing a distinguishable task; it can be likened to a human worker doing a specific job or using a particular skill. There are routines that exercise control (managers) and others that 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-

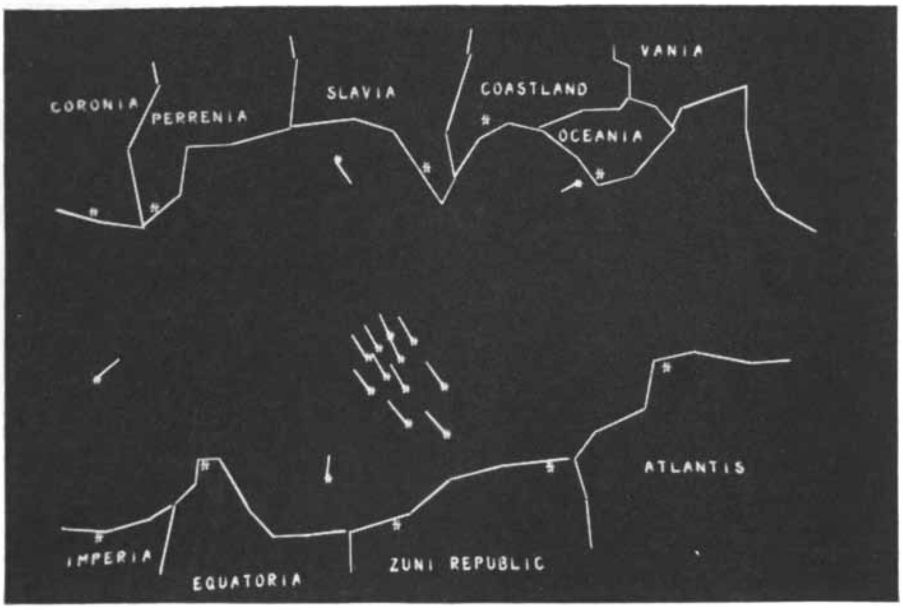



**CORPORATION NERVE CENTER** has evolved from a computer-assisted message-relay system developed by the Westinghouse Electric Corporation in the early 1960's. The diagram shows the scope of the system's activities in simplified form; some examples of its many functions are outlined in color. The center, 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

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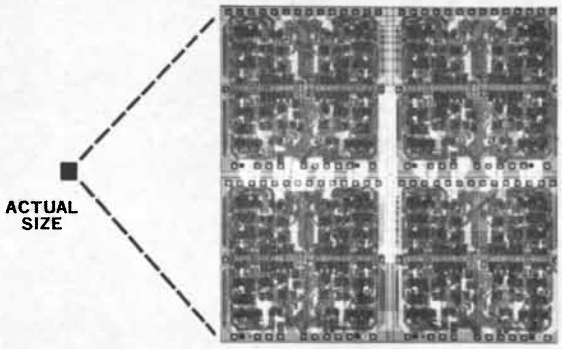
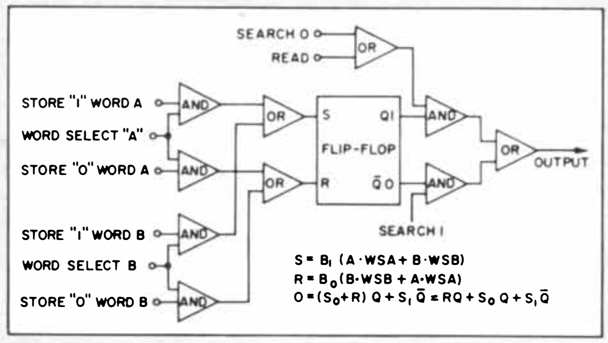



4 x 4 Array Before Wire Bonding

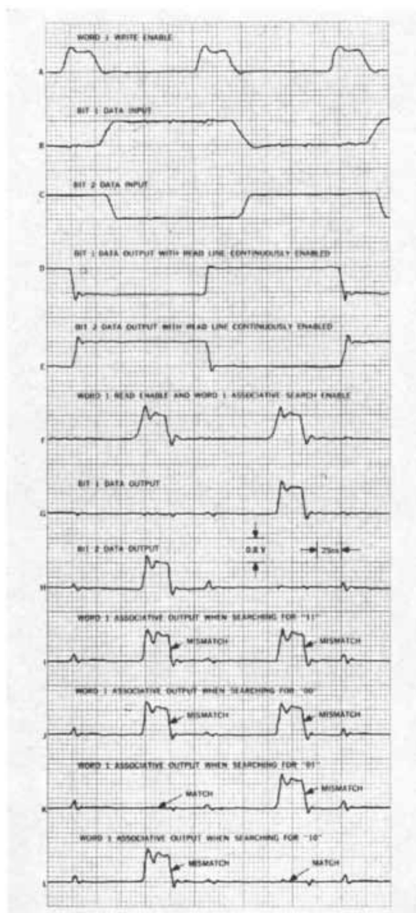



Block Diagram of a Dual Write Associative Memory Bit

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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