INSTRUCTION BOOK
511
(Part I)

AUTOMATIC DATA PROCESSING SYSTEMS FOR STAFF OFFICERS

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(This Instruction Book has been prepared under the supervision of the Commandant, US Army Signal School. It is provided for nonresident instruction conducted by the US Army Signal School. It reflects the current thought of this school and conforms to printed Department of the Army doctrine as closely as possible. Development and progress render such doctrine continuously subject to change.)

Section I. GENERAL

1. INTRODUCTION

a. Data is a particle of information. If a mass of data, such as flows in a weapons control system, could be used "as is," processing would not be necessary. The purpose of data processing is to do something to the data--something tangible. This tangible something involves classifying, sorting, calculating, summarizing, recording, and communicating data. Data processing cannot replace human judgment. It is, however, a powerful aid in making decisions based on more extensive, more complete, up-to-date, and accurate information than would normally be the case with a manual system.

b. Until recently, conventional punched card accounting techniques were viewed as the ultimate in the processing of data. The new electronic data processing techniques antiquate the punched card method of accounting in many instances. They can accomplish mass data processing never before thought possible.

c. Automatic data processing equipment does not "think," nor is it a "brain." It must be told what to do. As with punched card equipment, the end product can only be as good as the source material from which the data was extracted. This has given rise to the term "GIGO," meaning garbage in--garbage out. The advantage of automatic data processing equipment lies in the scope of what can be done with the information, once it is fed into the equipment, and the speed and accuracy of all the operations performed.

2. MILITARY REQUIREMENTS FOR AUTOMATIC DATA PROCESSING

a. New concepts of warfare, the development and use of complex weapons systems, and the requirements for processing large volumes of data have created a need by the Army for fast, reliable, and efficient methods for processing information revolving about these problems.

b. For military use, the computing system processes data within two major categories: mathematical computations and dissemination of raw information. The line between the two categories is hard to draw; many of the operations contain elements of both. In either application, computers produce speed and accuracy not attainable in the manual solution of the same problem.

(1) Mathematical computation. Within this category both tactical and administrative operations are performed. In the tactical aspect the solution of complex mathematical problems relating to ballistics, for example, can be accomplished only by computers to obtain the speed and accuracy required for artillery fire.

(2) Dissemination of raw information. This category involves the relatively simple process of recording, filing, sorting, comparing, analyzing, and compiling data. The processing of data is also applied to all arms and services and to many of the functions involved in military operations. Here, the task involves handling of records, statistics, factors, information, and data with the speed, accuracy, and reliability demanded by accelerated operations.

c. The availability of computing systems to meet the requirements of the military can be counted on to release people from performing tasks that can be better accomplished by electronic means. Thus, it enables the same people to do other tasks that require manual performance or to accomplish more than has been possible before the institution of automatic data processing systems.

d. The primary value of automatic data processing to the military lies in its ability to digest large volumes of information, to perform programed (pre-planned) operations on these data, to make quick evaluations based upon established criteria, to perform additional tasks as a result of these evaluations, and to display or transmit the final result or computation to the action authority, enabling him to make accurate and timely decisions.

e. In meeting the military requirements for automatic data processing, some of the general benefits gained from the system are as follows:

(1) Provision of timely data for close control and coordination of the operational, logistic, and administrative activities of a widely dispersed and highly mobile field army.

(2) Overall improvement in the speed and accuracy of data processing previously done by manual or electromechanical methods.

(3) Accomplishment of functions never before possible because of extreme difficulty, or because they were too time-consuming when performed by humans.

(4) Decrease of reaction time in the application of electronic countermeasures.

(5) Inherent capability to digest and greatly reduce the number of reports and miscellaneous papers generated by manual methods.

3. BACKGROUND TO AUTOMATIC DATA PROCESSING

a. The first modern automatic computer appeared on the scene in 1944. The story of the development of ideas, devices, and machines to compute goes back a long time into the past. Calculating and recording with numbers has been the focal point of interest for many thousands of years. One of the first examples of this interest was unearthed in Babylon in the form of baked clay tablets. These were used many centuries ago to record numbers and computation in business transactions of that day. Many of these tablets relate to agreements between farmers and priests about the rent of land from the temple in return for a fixed amount of the crop.

b. Slowly through the years that followed, the idea of counting by units of one developed into counting by units of ten. Devices were invented that enabled computing to be done in units of hundreds and thousands. The first of these was the abacus. At first this device consisted of a slab divided into areas. A supply of small stones to be placed in specific areas of the slab provided the counters to keep track of the numbers. Later, this evolved into a frame with movable markers that we know today as an abacus (fig 1).

c. The first mechanical machine was invented by the French mathematician Pascal in 1643. It had geared counter wheels which could be set to any one of ten positions from Ø to 9. Each gear had a little tooth for nudging the next counter wheel when it passed from 9 to Ø to carry 1 into the next column much in the same fashion as the automobile's mileage counter, the odometer.

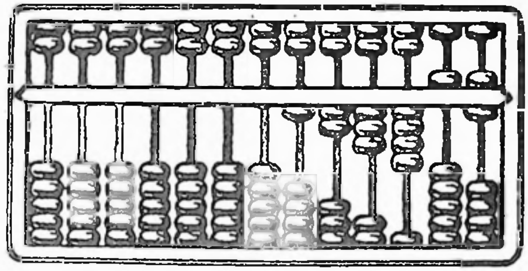

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Figure 1. Chinese abacus.

d. About thirty years later, in 1671, a German mathematician (Leibnitz) invented what turned out to be the first multiplying machine. This machine automatically controlled the amount of addition to be performed by a given digit. The improved versions of this machine were first sold commercially in the 1800's. Today, there are sophisticated adding machines and desk calculators which can be found in any business office.

e. Charles Babbage, an English professor of mathematics, first conceived in 1812 a machine that would not only add, subtract, and multiply, but would automatically perform a sequence of steps. He set out to build an automatic computer or "difference engine" as he called it. He intended to use the machine to compute mathematical tables by adding differences of numbers and print out the results. Once the starting data and the method of computation were placed into the machine, no further attention from a human operator would be necessary. For the next twenty years he worked on perfecting this engine. The British Government, during this period, provided interest and financial aid. When little progress was achieved at the end of this time, the Government dropped its support. Babbage, still optimistic, then began to plan for a more ambitious machine which he called an "analytical engine." It was to consist of three parts: the "store" where numbers were to be stored; the "mill" where arithmetical operations were to be performed on numbers taken from the store; and "sequence mechanisms" which would select the proper numbers from the store and instruct the mill to perform the proper operations.

f. Neither the difference engine nor the analytical engine was completed. Babbage died without a realization that his concepts were to become the foundation for today's high-speed computers.

g. The next development of historical value began in 1886. Dr. Herman Hollerith, a statistician and inventor, was working on the 1880 census of the United States. The census, six years after it had been taken was still not entirely summarized and tabulated. Hollerith made use of an idea that had been used for eighty years in weaving cloth--cards with punched holes to control the weaving pattern as used in the Jacquard loom. He knew that cards bearing human language were not readable by the machine, but that cards could be prepared using machine language, a language of punched holes that would be readable by a machine. Hollerith's experiments and machines were successful. This led to the development of machines using punched cards for business, accounting, and statistical purposes. A second inventor in the field of tabulators, James Powers, also developed a punched-card system. Where Hollerith used rectangular holes for his cards, Powers used round holes. The Powers idea is found in the punch-card systems of Remington Rand and Underwood-Samas, while the Hollerith idea can be found in the equipment of International Business Machines (IBM).

h. The first automatic digital computer that worked was called the "Complex Computer." It was designed and constructed at the Bell Telephone Laboratories in New York in 1939 to multiply and divide complex numbers. Its working elements consisted of ordinary telephone relays. The machine language used was simple. A code of ones and zeros represented the digits 0-9. Thus, four relays by their patterns of being energized or not being energized could express the code and designate each digit. The special purpose machine was completed and successfully demonstrated in 1940.

i. The first general purpose automatic digital computer was the Harvard IBM Automatic Sequence-Controlled Calculator. It started operations in 1944. This calculator was the joint enterprise of Professor Howard H. Aiken of Harvard University and the International Business Machines Corporation. This machine was in constant operation for many years, solving problems of military urgency. This computer was the first working realization of Babbage's analytical engine.

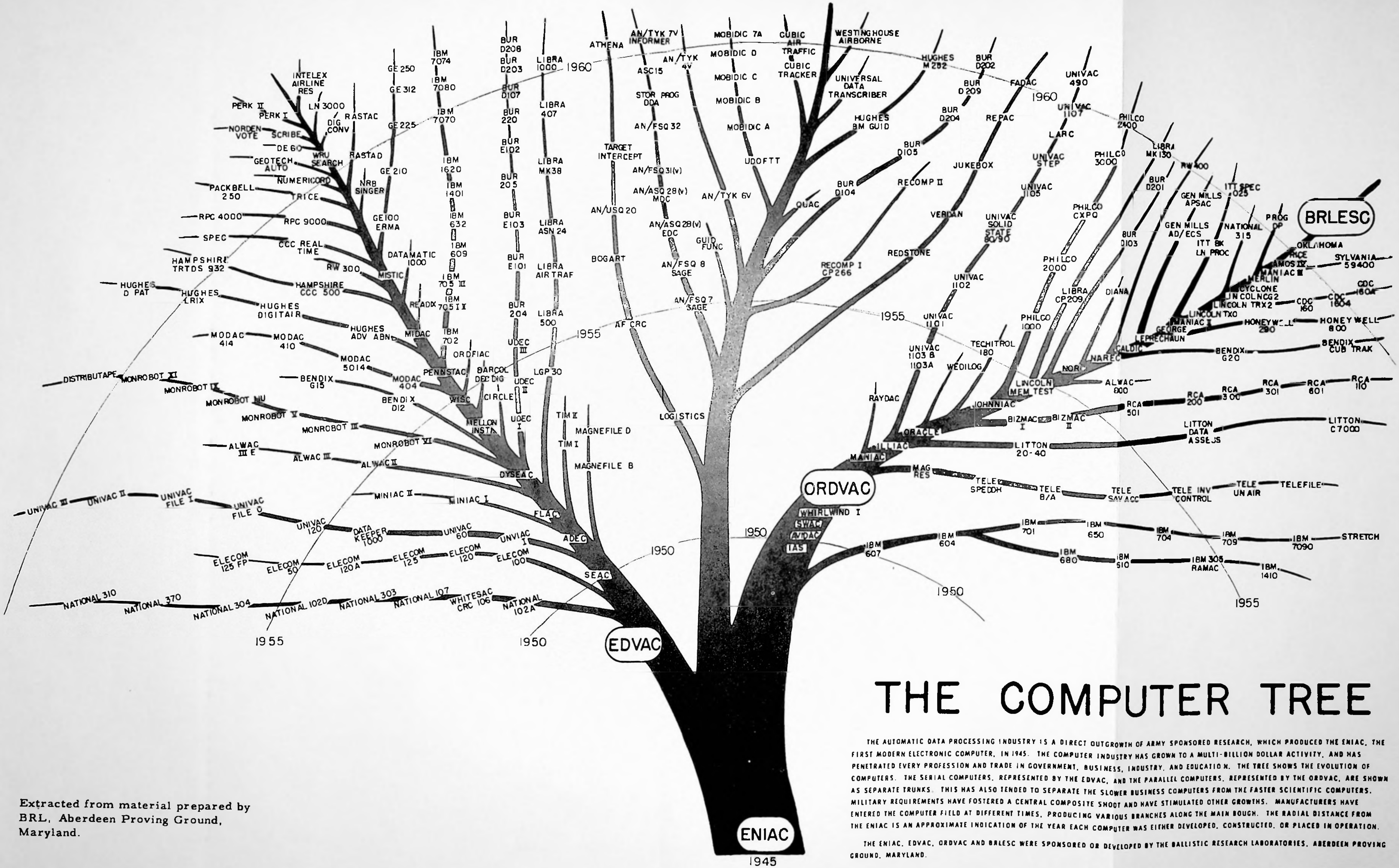
j. About the same time, from 1942 to 1946, an automatic electronic digital computer was being designed and constructed under the leadership of Dr. John W. Mauchly. This took place at the Moore School of Electrical Engineering at the University of Pennsylvania. Instead of relays, standard radio tubes and parts were used. The work at the Moore School produced, in 1946, the Electronic Numerical Integrator and Calculator, better known as the "ENIAC." It contained twenty registers where numbers could be stored or accumulated. It could add numbers at the rate of 5000 additions per second. It also contained a multiplier which would carry out from 360 to 500 multiplications per second, a divider-square-rooter, and other units.

k. Increased interest and much experimentation in computers were shown by many universities, businesses, and the Government during the intervening years from 1944 to 1952.

l. Great strides were taken in the development of computers since 1952. The speed of addition, for example, has gone over the 100,000 additions-per-second mark. Multiplication speed has increased to more than 10,000 per second. Storage capacity, or memory, accessible to the computing unit of a computer has been expanded from the 72 storage registers of the Harvard IBM calculator to literally an unlimited number of registers. Figure 2 illustrates the evolution of the computer.

m. A different type of computer was being developed almost concurrently with the digital computer. This was the analog computer, which computes by using physical analogs of numerical measurements.

n. Hybrid computers are also being developed and applied. This type of machine uses an analog computer in one part of the system and a digital computer in other parts of the system.



THE COMPUTER TREE

THE AUTOMATIC DATA PROCESSING INDUSTRY IS A DIRECT OUTGROWTH OF ARMY SPONSORED RESEARCH, WHICH PRODUCED THE ENIAC, THE FIRST MODERN ELECTRONIC COMPUTER, IN 1945. THE COMPUTER INDUSTRY HAS GROWN TO A MULTI-BILLION DOLLAR ACTIVITY, AND HAS PENETRATED EVERY PROFESSION AND TRADE IN GOVERNMENT, BUSINESS, INDUSTRY, AND EDUCATION. THE TREE SHOWS THE EVOLUTION OF COMPUTERS. THE SERIAL COMPUTERS, REPRESENTED BY THE EDVAC, AND THE PARALLEL COMPUTERS, REPRESENTED BY THE ORDVAC, ARE SHOWN AS SEPARATE TRUNKS. THIS HAS ALSO TENDED TO SEPARATE THE SLOWER BUSINESS COMPUTERS FROM THE FASTER SCIENTIFIC COMPUTERS. MILITARY REQUIREMENTS HAVE FOSTERED A CENTRAL COMPOSITE SHOOT AND HAVE STIMULATED OTHER GROWTHS. MANUFACTURERS HAVE ENTERED THE COMPUTER FIELD AT DIFFERENT TIMES, PRODUCING VARIOUS BRANCHES ALONG THE MAIN BOUGH. THE RADIAL DISTANCE FROM THE ENIAC IS AN APPROXIMATE INDICATION OF THE YEAR EACH COMPUTER WAS EITHER DEVELOPED, CONSTRUCTED, OR PLACED IN OPERATION.

THE ENIAC, EDVAC, ORDVAC AND BRLESC WERE SPONSORED OR DEVELOPED BY THE BALLISTIC RESEARCH LABORATORIES, ABERDEEN PROVING GROUND, MARYLAND.

Extracted from material prepared by BRL, Aberdeen Proving Ground, Maryland.

Figure 2. The computer tree.

4. MAJOR CLASSIFICATIONS OF COMPUTERS

The names of the two major classifications of computers very accurately describe the computers themselves. Analog computers operate by analogy; that is, they compute by using physical quantities which represent the variables of the problem being solved. Digital computers operate on digits; that is, they compute by using numbers to represent all the variables of the problem. It is not possible to make a blanket statement as to which method is better; the choice depends on the application.

5. THE ANALOG COMPUTER

An analog computer is essentially a device which accepts continuous measurements and produces continuous solutions to mathematical equations. In an analog computer, the components of electronic circuits, gear mechanisms, and other devices can be arranged to behave just like the relationships of variables in a mathematical equation--to behave analogously to an equation. Frequently, the equations are those which have been developed for thoroughly describing a physical situation such as the motions of a projectile in flight.

a. To handle information, an analog computer must translate the mathematical relationships of a problem into analogous physical relationships of its operating components--electronic circuit elements, gear ratios, shaft rotation, etc. Continuous measurements are then fed into the computer, using the information to solve thousands of complex, interrelated equations, and producing answers as a continuous record on a calibrated scale. Answers are traced on a graph by a pen, or are indicated on a plotting board, or are shown on a dial.

b. There are many common uses for simple analog devices. One example is the automobile speedometer. It converts the rate of turning of a cylindrical shaft into a numerical approximation of speed in terms of miles per hour. Here the analog of speed is a shaft rotation.

c. Another example of the analog computer is the slide rule, which is based on the fact that two numbers can be multiplied by adding their logarithms. On a slide rule we actually add analogs of logarithms in the form of lengths proportional to them. However, the scales printed on the slide rule permit us to read the numbers themselves, and to disregard the fact that we are actually dealing with their logarithms.

d. These examples of analog computers are quite elementary ones. However, these computers are also used for many complex purposes. Many fire control systems for tracking planes are analog computers. Variables, such as wind drift, plane speed, ship speed, range, and direction are continuously fed into these devices. Their high-speed computing action enables gunners to anticipate the changing position of a plane, and fire a round which will hit the plane a few moments later.

e. The analog computer possesses two inherent limitations. First, it cannot easily be used for dissimilar problems. The computer itself is a mechanical or electrical analogy to an equation; changing the equation means changing the components of the computer. Second, the analog computer is precise only to two or three significant figures, depending upon the degree of precision of its mechanical or electrical components. Accuracy then depends not only on the accuracy of the input data but also on the instruments which present the answers.

6. THE DIGITAL COMPUTER

a. Digital computers have no physical variables to be measured; rather, the quantities are represented by discrete (discontinuous) quantities--digits. Many different devices may represent these digits. The most common are gear positions and electric or magnetic conditions. In every case, however, these devices are not continuous; they are only distinct states, such as on or off. A desk calculator or adding machine, for example, uses separate gear positions to represent quantities. In one column there are only the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, with nothing between digits. An electronic computer uses an electrical current which is either on or off, or a magnetization which is either one way or the other. Various values of current or strengths of magnetization are not considered.

b. The digital computer accepts information in the form of coded alphabetical and numerical characters, and processes this information in accordance with a predetermined sequence (the program) that can be varied as required.

c. This type of computer can process ordinary numbers or alphabetic characters, or a combination of both with no trouble. It can handle continuously variable data by sampling the value of the function at regular intervals and giving it a numerical representation. It can do more types of work than an analog computer, and once the information is translated into digital form, it even "remembers" the decimal point in its precision. The accuracy of the digital computer's work can easily be checked by inverse operations, by identical parallel operations compared for identical answers, or by many other means. Furthermore, the inherent accuracy of this type of computer is phenomenal. A record was kept of errors in the first 6 weeks of operation of an installed computer. In this period of 724 hours of operation, the machine performed 10,936,296,000 operations with 31 errors; 19 of these were corrected on a second reading, 10 were due to dust, and 2 were of a mechanical nature.

d. General-purpose digital computing systems are far simpler than analog networks (although some of them are much larger); they can basically add, compare, and discriminate between relative magnitudes of stored information. They subtract by inverse addition, multiply by repeated addition, and divide by alternately performed repeated additions and subtractions. Depending on their discriminatory abilities, the digital computers can select paths of action, sort information, or control the starting or stopping of a process.

7. TYPES OF DIGITAL COMPUTERS

Digital computers are classified according to the specific purpose for which they are intended. Their design, size, amount of peripheral equipment, etc., are dictated by the nature of the computations and processes they perform. These classifications include:

a. Scientific or Engineering. These computers are designed for the solution of extremely complex mathematical problems. Such computers permit the programer to sequence steps in a complicated equation. The equipment performs the involved computations at milli- and micro-second speeds, thereby relieving the mathematicians of the time-consuming task of adding, subtracting, multiplying, extracting roots, and other mathematical computations. Scientific or engineering type computers are characterized by a small input. Input may be digested in a matter of minutes, while the arithmetic and logic unit performs in an hour the work that requires days or weeks to do manually. Most of the computers used in these fields are now solving problems concerned with radar and space.

b. Business or Logistics. The computers used for business- or logistics-type operations are designed to store large quantities of information (inventory data, personnel and payroll information, etc.) and to perform relatively simple calculations on a high volume of input, with variable volumes of output. In business-type operations, the electronic processes (functioning at milli- and micro-second speeds) frequently are limited by the slow rate of input and output devices. These devices are electromechanically controlled and cannot feed information fast enough into the electronically controlled computer. To solve this problem a connection is made between these devices with a buffer unit. The buffer unit accepts input information at the speed of the input device and feeds it at speeds required by the computing equipment to perform its calculations. The solution to the problem in the computer is then fed into a buffer unit connected to the output device. This information is fed from the buffer unit at the slower rates of speed required by the output device.

c. Special Purpose. A computer designed to perform either a single function or a limited number of functions is classified as special purpose. Such computers are smaller and more compact than either the scientific, engineering, business, or logistics-type computers. A military example of the special purpose computer is one which is integral to a fire control system and is used to compute data required for firing on a particular target.

d. General Purpose. This classification is given to computers designed to perform more than one job. It usually has an internally stored program which can be modified or replaced by another program. This allows a great deal of flexibility in the types of work a general purpose computer can do. Changing from supply to payroll computations is easily done by simply reading in the appropriate program.

8. CLASSES OF AUTOMATIC DATA PROCESSING EQUIPMENT

a. Size. The size of the computer, specifically the central processing unit, determines the class to which it belongs. At present there are three classes: small, medium, and large. Size does not necessarily mean physical size, although a large-scale computer is usually larger in physical size than a medium-scale computer. Size means the capacity of the system to store data, its control, and its ability to perform arithmetic and logic operations with respect to these variables. The size of the computer is reflected in the purchase price:

Large - - - over $500,000.

Medium - - from $100,000 to $500,000.

Small - - - under $100,000.

b. Access Time. A common method of classifying and evaluating memory devices involves the unit's access time. Access time is the length of time between the instant at which the arithmetic and logic unit requires information from the memory unit and the instant at which the information is delivered from storage to the arithmetic and logic unit. In reality, access time is the amount of time it takes to contact a specified memory location and transmit the information stored there to some other place within the computer where it is needed. This time is measured in milliseconds (thousandths of a second), microseconds (millionths of a second), or nanoseconds (billionths of a second).

9. RELIABILITY OF COMPUTERS

a. The first computers of the 1940's were not very reliable. The equipment and parts of which they were made had not been engineered to be exceedingly accurate. The programers for a problem usually had to program the checks they wanted used by doing the problem in a different way. For example, A times B would be computed in the equipment differently from B times A. Both operations would be programed, and an instruction to compare the results would also be programed.

b. Present-day computers can operate with extreme reliability. Automatic checking of various kinds is built into the computer to maintain error-free processing. However, random errors do occur due to machine malfunctions. These machine faults are of two kinds: intermittent and constant. An intermittent fault may be due to a momentary speck of dust between a magnetic reading head and the magnetic tape, so that a 1 is read as an Ø. A constant fault may be due to a component going below par so that electric pulses do not pass through it properly. For both these faults there are diagnostic programs or service routines to locate the point where the computer made the error.

c. To avoid loss of information, checking binary digits (parity bits) may be carried by the computer along with each character of information to maintain an even or odd condition. For example, for odd parity, if the number of 1's in the code for a character is even (011101), the checking bit is an additional 1 (0111011). For even parity, if the number of 1's in the character is odd (100110), the checking bit is Ø (100110Ø). This always results in an odd sum if the character and parity bits are added together. The machine automatically counts bits in the character code at numerous points and can tell if a character is wrong, goes back to a preceding point, usually at the beginning of the last routine, and recomputes.

d. Faults caused by improper programing are often difficult to diagnose. To correct this type of fault, a "debugging" procedure must be used. Debugging is the term given to the process of locating and correcting errors in a program. A series of trial runs is made of the program until the program is known to be free of errors. Any computer faults incurred during the trial runs are diagnosed, and the program is corrected to eliminate the cause of the faults. There are several types of service routines which can be used to aid the debugging process. Thus, it can be seen that every program must be carefully reviewed to eliminate faults in programing.

e. There are other types of computer faults which indicate an erroneous condition. On all computers, these faults are referred to as errors and are indicated on the operator's console. Although this is a partial listing, the following errors are considered serious enough to warrant the halt of computer operations until cleared:

(1) Input errors, such as clerical errors made during the preparation of the coding for input.

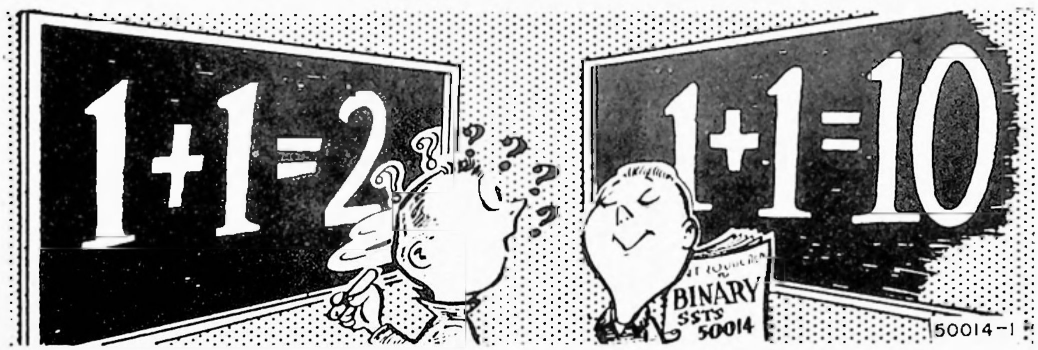
(2) Logical errors made during analysis and programing of the problem.

(3) Operator intervention errors, such as improper procedures at the computer control panel.

10. INTRODUCTION

a. Familiarity with machine language is essential before the functional elements of the machine are discussed. An electronic computing machine not only must have a language it understands, but which can also be interpreted by the operator. The basis for the language of most computers is the binary system of notation. This is little more than a different numbering system. It is, however, a convenient method of presenting data in a form compatible with electronic circuitry.

b. A digital computer is a calculating machine that computes number problems just as people do. To carry out its operations automatically, numbers and other information must be supplied to the computer in a form the machine can "understand." In almost all digital computers, this "understandable information" is fed in the form of electrical pulses. Or the information is represented by the operated or nonoperated states of many relays; or the conducting or nonconducting states of many vacuum tubes or transistors; or the storage states of many magnetic cores. These devices: relays, tubes, transistors, and magnetic cores are all called bistable because they are always in one of two stable states.



c. It's not difficult to see that the decimal digits from 0 to 9 could be represented by the operated state of ten of these bistable devices. For that matter, any decimal digit can be represented by an electrical pulse on one of ten wires. However, it is wasteful to use ten pulses or operate ten devices to represent the decimal digits. The job can be done with fewer pulses or operations by using the BINARY NUMBERING SYSTEM instead of the decimal system. In the binary system, we count by powers of two instead of powers of ten as in the familiar decimal system.

11. WHY LEARN THE BINARY SYSTEM?

a. Perhaps you're wondering why you must know and learn how to use the binary numbering system. True, the actual calculations involving binary numbers are made electronically by the computer. However, knowing how to use binary arithmetic will help you to understand the logic behind many of the circuits that make up a digital computer.

b. The purpose here is to explain the binary numbering system, how to convert decimal numbers into binary numbers and how to convert binary numbers into their decimal equivalents. Also, how to add, subtract, multiply, and divide using the binary system. Before you start, read this section with a pencil in your hand so that you can work out the problems as you read. This way you'll learn by doing.

12. BINARY NUMBERING SYSTEM USES TWO DIGITS--0 AND 1

a. All of us use the decimal numbering system everyday and are familiar with its basic rules. We count by tens because we have ten fingers. This is the natural way to count. However, the decimal system is a very inefficient and complex system when used in digital computers that must perform arithmetic operations automatically. So the binary numbering system was adapted for computers because it proved to be more efficient than the decimal system.

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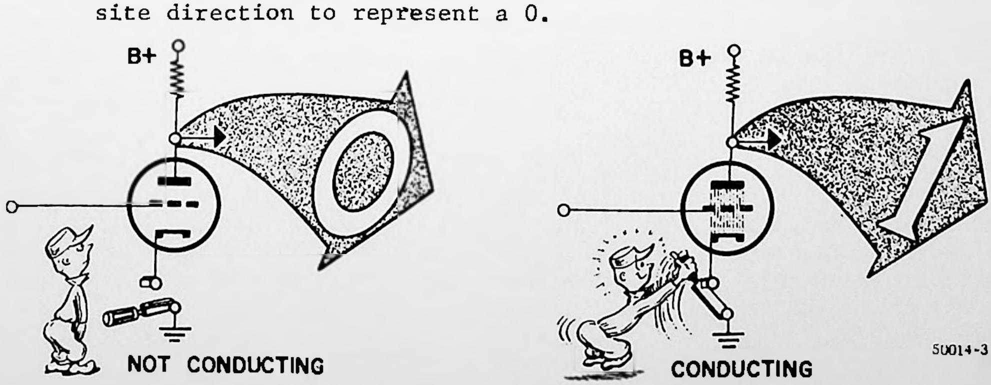
b. You know that the decimal numbering system uses 10 digits. Now, the word BINARY means two, so the binary system differs in that it uses just two digits: 0 and 1. These two digits are called BITS, which is a contraction for Binary digITS.

c. There are two main advantages to using binary arithmetic in computing systems:

(1) Many components and circuits are available that have two states that can be used to represent the two digits of the binary system. For example, a relay is either operated or not operated. We can say that the operate condition represents a 1, and the nonoperate condition represents a 0. Similarly, a vacuum tube or transistor can represent a 1 when it conducts and a 0 when it is not conducting. A magnetic core, another bistable device, can be saturated (magnetized) in one direction to represent a 1 or saturated in the opposite direction to represent a 0.



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(2) The second main advantage in using the binary system is that arithmetic operations using the binary system are much simpler than using the decimal system. Operations are resolved into only two absolute sets of conditions of either 1 or 0. The binary system enables a computer to work on a simple ON-OFF basis. A computer using binary arithmetic to solve a problem is small and simple, whereas a computer using the decimal system to solve the same problem would be more complicated. In a large complex digital computer, the decimal system would require the use of enormous quantities of equipment, resulting in unusually high cost and enormous space requirements. Use of the binary system eliminates the need for 10 different states of 0 through 9. On the other hand, combinations of 0 and 1 (circuits that are either ON or OFF) can represent any number, letter, or symbol that is to be handled by the computer. Now that you know why we use the binary numbering system in digital computers, let's compare the two systems in more detail.

13. COMPARING DECIMAL AND BINARY SYSTEMS

a. In the decimal system, the value of a number depends on the position of its digits. For example, in the decimal numbers, 75 and 75,222, the 5 in 75 is really treated as a 5 (that is, it has the value of 5), but the 5 in 75,222 really means 5,000. So you see, changing the position or place of a digit in a number changes the digit value.

b. Take another example: just what does 923 mean? For one thing, 923 does not mean 9 + 2 + 3 nor 9 x 2 x 3. It really means $9 \times 10^2 + 2 \times 10^1 + 3 \times 10^0$. The reason for this, as you probably know, is that 10 is the radix or base of the decimal system. Radix is the number of discrete digits used in a numbering system; i.e., in the decimal system we use the digits 0, 1, 2, 3, ..., and 9; in the binary system we use 0 and 1, in that sequence. For example, in decimal notation the number 10 is shown as 10, indicating there is one 10 and 0 ones; in binary notation the same numerical symbols (10) stand for the value of two. Positional notation and the base or radix determine what numerical values are given to number combinations. The positional or place values and the equivalent powers of 10 of the decimal system are given in table I.

TABLE I

POSITIONAL VALUES OF THE DECIMAL SYSTEM

POSITION	MILLIONS	HUNDRED THOUSANDS	TEN THOUSANDS	THOUSANDS	HUNDREDS	TENS	UNITS
VALUE	1,000,000	100,000	10,000	1,000	100	10	1
POWER	10^6	10^5	10^4	10^3	10^2	10^1	10^0

c. Using the information in table I, let's see what are the positional values in the number 75,222. First we'll set down the number and the positional values in two rows. Then we'll prove it out by multiplying the two rows and adding up the results.

POSITIONAL VALUES OF 75,222

ROW A:	7	5	2	2	2
ROW B:	10^4	10^3	10^2	10^1	10^0

MULTIPLY ROW A TIMES ROW B

7	x	10^4	=	70,000
5	x	10^3	=	5,000
2	x	10^2	=	200
2	x	10^1	=	20
2	x	10^0	=	2
ADDING THE RESULTS, WE GET:				75,222

14. WHY USE POWERS OF 10?

Why should powers of 10 be used in these numbers rather than powers of 8 or 12 or some other number? The answer is that other numbers might perfectly well be used instead of 10. Actually, it boils down to this: If men had 12 fingers instead of 10, we'd use powers of 12. But if we had only 8 fingers, we'd use powers of 8. As a matter of fact, any positive number except 1 could be used as a base in writing numbers. The binary system uses 2 as a base and represents a number by powers of 2. A power of 2, as of any number, is simply the result of self-multiplication. See the example shown at the right.

POWERS OF 2
$2^2 = 2 \times 2 = 4$
$2^3 = 2 \times 2 \times 2 = 8$
$2^4 = 2 \times 2 \times 2 \times 2 = 16$
$2^5 = 2 \times 2 \times 2 \times 2 \times 2 = 32$
$2^6 = 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$

15. BINARY SYSTEM USES POWERS OF 2

a. The binary system works like the decimal system--just substitute the powers of 2 for the powers of 10. Thus, if we take the number 1111111, for example, we get the following:

IN THE DECIMAL SYSTEM:

$$1111111 = 10^6 + 10^5 + 10^4 + 10^3 + 10^2 + 10^1 + 10^0 = 1,111,111$$

IN THE BINARY SYSTEM:

$$1111111 = 2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0 = 127$$

b. The positional values and the equivalent powers of 2 are given in table II.

TABLE II

POSITIONAL VALUES OF THE BINARY SYSTEM

POSITION	SIXTY-FOUR	THIRTY-TWO	SIXTEEN	EIGHT	FOUR	TWO	UNITS
VALUE	64	32	16	8	4	2	1
POWER	2^6	2^5	2^4	2^3	2^2	2^1	2^0

c. Compare table I on page 18 with table II. Notice that the decimal system can represent numbers more compactly than the binary system. The reason is, of course, that the decimal system uses a larger base (10). But the binary system can represent numbers with fewer symbols because of its smaller base (2). Remember, in the binary system, the symbol 1 indicates that a particular column (place or position) contains a power of 2: the symbol 0 indicates that a column does not contain a power of 2. These two symbols, 1 and 0, expressed as one (1) and zero (0) are all we need to represent any number as the sum of powers of 2.

16. HOW TO CONVERT DECIMAL NUMBERS TO BINARY NUMBERS

a. Using the symbols 0 and 1, let's convert the decimal numbers 0 through 10 into their binary equivalents. The first thing to do is to construct a table like table III at the right. The powers of 2 appear across the top of table III and the decimal numbers down the left side of the table.

b. Now if a power of 2 appears in the decimal number at the left, place a 1 in the column in which that power of 2 appears. If a power of 2 is not used, place a 0 in that column. Now, convert the decimal numbers, following the steps given below.

(1) The binary 0 is the same as the decimal 0. Since no power of 2 is used, place a 0 in each column.

(2) Next, the decimal number 1 is equal to 2^0. So place a 1 in the 2^0 column. Also place zeros under all the other powers of 2.

TABLE III

TABLE USED TO CONVERT DECIMAL NUMBERS INTO BINARY NUMBERS

DECIMAL NUMBERS	BINARY NUMBERS					
	2^5	2^4	2^3	2^2	2^1	2^0
	32	16	8	4	2	1
0						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

DECIMAL NUMBERS	BINARY NUMBERS					
	2^5	2^4	2^3	2^2	2^1	2^0
	32	16	8	4	2	1
0	0	0	0	0	0	0
1	0	0	0	0	0	1

(3) The decimal number 2 is equal to 2^1, so place a 1 under 2^1 and zeros under all other powers of 2.

DECIMAL NUMBERS	BINARY NUMBERS					
	2^5	2^4	2^3	2^2	2^1	2^0
	32	16	8	4	2	1
~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
~~1~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~
2	0	0	0	0	1	0
3	0	0	0	0	1	1

(4) Next, the decimal number 3 equals $2^1 + 2^0$, so place a 1 in each of these columns and zeros in the rest.

(5) The decimal number 4 equals 2^2, so place a 1 under 2^2 and zeros under the other powers of 2.

DECIMAL NUMBERS	BINARY NUMBERS					
	2^5	2^4	2^3	2^2	2^1	2^0
	32	16	8	4	2	1
~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
~~1~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~
~~2~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~0~~
~~3~~	~~0~~	~~0~~	~~0~~	~~0~~	~~1~~	~~1~~
4	0	0	0	1	0	0
5	0	0	0	1	0	1

(6) Next, the decimal number 5 equals $2^2 + 2^0$ or 4 + 1. So place a 1 under each of those powers of 2 and zeros under the rest.

(7) Do the same for the rest of the numbers. Table IV shows how your table should look when you're finished. Notice that the binary numbers for 20, 30, 40, and 50 are included.

TABLE IV
CONVERSION OF DECIMAL NUMBERS INTO BINARY NUMBERS

DECIMAL NUMBERS	BINARY NUMBERS					
	2^5	2^4	2^3	2^2	2^1	2^0
	32	16	8	4	2	1
0	0	0	0	0	0	0
1	0	0	0	0	0	1
2	0	0	0	0	1	0
3	0	0	0	0	1	1
4	0	0	0	1	0	0
5	0	0	0	1	0	1
6	0	0	0	1	1	0
7	0	0	0	1	1	1
8	0	0	1	0	0	0
9	0	0	1	0	0	1
10	0	0	1	0	1	0
20	0	1	0	1	0	0
30	0	1	1	1	1	0
40	1	0	1	0	0	0
50	1	1	0	0	1	0

17. ANOTHER WAY TO CONVERT DECIMAL NUMBERS INTO BINARY NUMBERS

a. Conversion of decimal numbers into binary numbers by means of a table is a tedious and painstaking job. An easier way to convert a decimal number into a binary number is to divide the decimal number by 2, and the answer again by 2, and so on, until you have a remainder of only 1.

b. For example, convert the decimal number 37 into its binary equivalent as shown at the right. To obtain the binary equivalent, read the remainders from bottom to top. Thus, the binary equivalent of 37 equals 100101. Notice that throughout each step of division, all numbers are either exactly divisible by 2 or divisible by 2 with a remainder of 1. If 2 divides evenly into a number, place a 0 to the right of that division. When 2 does not divide evenly, place a 1 to the right of that division. Continue until further division by 2 is impossible. Read the answer in the binary system from BOTTOM TO TOP.

2/37	
2/18	1 remainder
2/ 9	0 remainder
2/ 4	1 remainder
2/ 2	0 remainder
2/ 1	0 remainder
0	1 remainder

c. Now try two more examples: convert decimal numbers 55 and 22 to binary numbers as follows:

CONVERTING	2/55	
55	2/27	1
TO A	2/13	1
BINARY	2/ 6	1
NUMBER	2/ 3	0
	2/ 1	1
	0	1

55 therefore equals 110111

CONVERTING	2/22	
22	2/11	0
TO A	2/ 5	1
BINARY	2/ 2	1
NUMBER	2/ 1	0
	0	1

22 therefore equals 10110

d. Pick numbers at random and practice converting them into binary numbers. With a little practice you'll be able to convert any decimal number into its binary equivalent.

18. HOW TO CONVERT BINARY NUMBERS INTO DECIMAL NUMBERS

a. Even though binary arithmetic is easier to use than decimal arithmetic, we are accustomed to thinking of numbers in the decimal system. Therefore, we must be able to convert the binary number into its decimal equivalent. The conventional way of doing this is by using the method of powers. As you know, each place position in the decimal system is a power of 10. For example, the number 52 means 50 + 2, which means, in turn, $5 \times 10^1 + 2 \times 10^0 = 52$.

b. Take another example: the decimal number 5,527 means 5,000 + 500 + 20 + 7 which equals $5 \times 10^3 + 5 \times 10^2 + 2 \times 10^1 + 7 \times 10^0 = 5,527$.

c. Similarly, every place position in the binary number represents a power of 2. Thus, to convert the binary number 1110011 to a decimal number, first write the digits of the number one after the other in a row (Row A below). Next, write the powers of 2 in another row (Row B) directly below the digits of the binary number. Use as many powers of 2 as there are digits in the number. Start at the extreme right with the zero power of 2 because 2^0 equals 1.

POSITIONAL VALUES OF 1110011

ROW A:	1	1	1	0	0	1	1
ROW B:	2^6	2^5	2^4	2^3	2^2	2^1	2^0

MULTIPLY ROW A TIMES ROW B

$1 \times 2^6 = 64$

$1 \times 2^5 = 32$

$1 \times 2^4 = 16$

$0 \times 2^3 = 0$

$0 \times 2^2 = 0$

$1 \times 2^1 = 2$

$1 \times 2^0 = 1$

ADDING THE RESULTS, WE GET: 115

So, the binary number 1110011 represents the decimal number 115. Now, try another example. Convert binary number 101101 to a decimal number.

POSITIONAL VALUES OF 101101

ROW A:	1	0	1	1	0	1
ROW B:	2^5	2^4	2^3	2^2	2^1	2^0

MULTIPLY ROW A TIMES ROW B

$1 \times 2^5 = 32$

$0 \times 2^4 = 0$

$1 \times 2^3 = 8$

$1 \times 2^2 = 4$

$0 \times 2^1 = 0$

$1 \times 2^0 = 1$

ADDING THE RESULTS, WE GET: 45

So, the binary number 101101 represents the decimal number 45.

19. ANOTHER SYSTEM OF BINARY-TO-DECIMAL CONVERSION

a. Adding powers of 2 to obtain the decimal equivalent of a binary digit can become too tedious and lengthy, especially in the case of large numbers. The DOUBLE-DABBLE system is an easier and more rapid method of binary-to-decimal conversion. The rules for using the double-dabble system are given below:

RULES FOR DOUBLE-DABBLING

RULE 1. START WITH FIRST BIT AT THE EXTREME LEFT.

RULE 2. IF THE NEXT BIT IS A 0, DOUBLE WHAT YOU HAVE.

RULE 3. IF THE NEXT BIT IS A 1, DOUBLE WHAT YOU HAVE AND ADD 1. ADDING 1 IS CALLED DABBLING.

b. Figure 3 shows you how to use the double-dabble system to convert the binary number 10101 to a decimal number. Notice in part A that you start with the left-most bit and work to the right (rule 1). First you double 1 to get 2 because the next bit is a 0 (rule 2). In part B, you dabble the 2 to get 5 because the next bit is a 1 (rule 3). Next, you double the 5 to get 10 because the next bit is a 0 (rule 2). Finally, in part D, you dabble the 10 to get 21 because the last digit is a 1 (rule 3). Thus the binary 10101 equals 21. Easy isn't it? Now try another example.

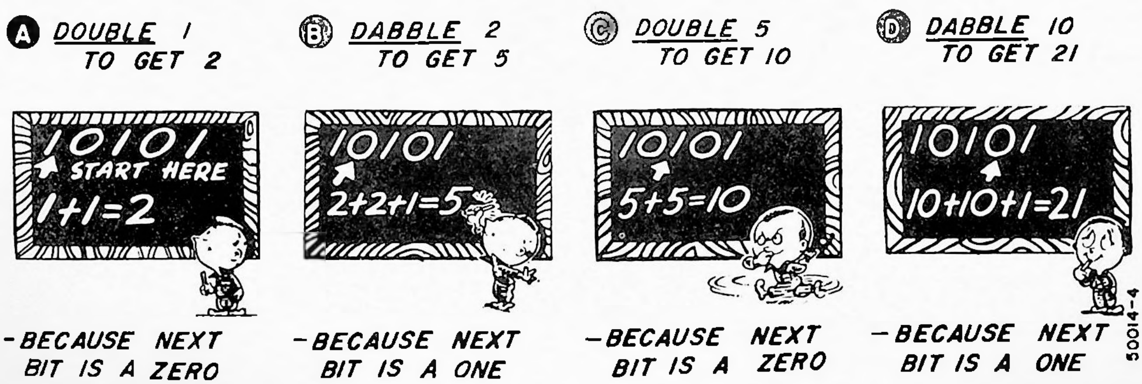


Figure 3. How to use the double-dabble system to convert a binary number.

(1) Sample problem. Convert the binary 1011 to its decimal equivalent. Follow the steps below carefully.

Step 1. Starting with the left-most bit, double 1 to get 2 because the next bit is a 0.

Step 2. Then dabble 2 to get 5 because the next bit is a 1.

Step 3. Finally, dabble 5 to get 11 because the last bit is also a 1.

Therefore, 11 is the decimal equivalent of the binary 1011.

(2) Sample problem. Convert the binary 1110011 to its decimal equivalent. Follow the steps below carefully.

Step 1. Starting with the left-most bit, dabble 1 to get 3 because the next bit is a 1.

Step 2. Then dabble 3 to get 7 because the next bit is also a 1.

Step 3. Next, double 7 to get 14 because the next bit is a 0.

Step 4. Double 14 to get 28 because the next bit is a 0 too.

Step 5. Then dabble 28 to get 57 because the next bit is a 1.

Step 6. Finally, dabble 57 to get 115 because the last bit is a 1.

Therefore, 115 is the decimal equivalent of the binary 1110011.

c. So far, you've learned how to convert a decimal number into the binary system and convert the binary number to the decimal system. Next you'll learn how to use the binary numbering system to do the basic arithmetic operations of addition, subtraction, multiplication, and division.

20. HOW TO ADD BINARY NUMBERS

a. Binary addition is similar to addition in the decimal system. There are three rules to remember when adding binary numbers:

RULES FOR BINARY ADDITION

RULE 1. 0 + 0 = 0

RULE 2. 1 + 0 = 1

RULE 3. 1 + 1 = 0 WITH A CARRY OF 1. ADD THE CARRY TO THE DIGITS IN THE NEXT COLUMN TO THE LEFT.

b. The first two rules are easy to apply. For example, adding the binary number 11 to the binary number 100 produces the binary sum of 111.

BINARY SYSTEM		DECIMAL SYSTEM
100	equals	4
11	equals	3
111	equals	7

c. In binary arithmetic, addition requires the "carrying" of a number just as it does in the decimal system. For example, when you add two decimal numbers, such as 23 and 9, you start with the units column at the extreme right and total each column. Since 3 and 9 are greater than 10, you bring down the units 2, and carry the tens to the next column. Then you add the carry to the tens, 10 + 20 to get 30. Finally, add the tens to the units, 30 + 2 to get 32.

```
23
 9
——
 2 units
10 carry
20 tens
——
32 sum
```

d. The principle of carrying holds true for the binary system too. Here is where rule 3 becomes important. Rule 3 states that in adding 1 + 1 we must substitute the lowest digit in the binary system, which is 0, for the highest digit, 1, and increase the digit in the next column to the left by 1. For example, let's add the binary numbers 1101 and 1001. Refer to figure 4.

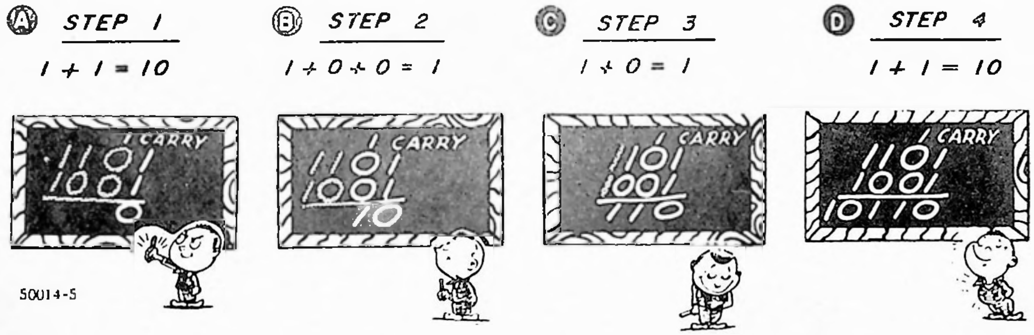


Figure 4. How to add binary numbers.

Step 1. Starting with the units column at the extreme right of the binary number, add 1 + 1 = 10. Write 0 and carry 1 as stated in rule 3 (part A of fig 4).

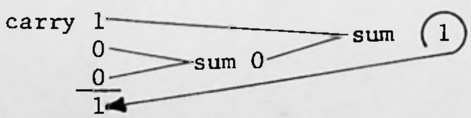
Step 2. Add 0 + 0 + 1 (carried) = 1 (rule 2). Write 1 in the second column (part B).

Step 3. Add 0 + 1 (no carry) = 1 (rule 2). Write 1 in the third column (part C).

Step 4. Add 1 + 1 (no carry) = 10 (rule 3). Write 10 for the last addition (part D).

Answer: 10110.

Another way of looking at the matter of the carry is by taking another look at figure 4B. You know that the binary system permits only two characters to be manipulated at any one time. Thus, the illustration could be diagrammed as follows:



Check your addition by converting the binary numbers to the decimal system, using the DOUBLE-DABBLE system you learned previously.

1101: First dabble 1 to get 3.

Next, double 3 to get 6.

Finally, dabble 6 to get 13.

1101 = 13

1001: First double 1 to get 2.

Next, double 2 to get 4.

Finally, dabble 4 to get 9.

1001 = 9

10110: First double 1 to get 2.

Next, dabble 2 to get 5.

Then, dabble 5 to get 11.

Finally, double 11 to get 22.

10110 = 22

21. HOW TO SUBTRACT BINARY NUMBERS

a. You can also subtract binary numbers from other binary numbers just as in the decimal system. For example, subtract the binary number 11 from 111:

BINARY SYSTEM		DECIMAL SYSTEM
111	equals	7
-011	equals	-3
100	equals	4

b. This is an easy example because the digit 1 is subtracted from another digit just as in the decimal system. It gets a little harder when you subtract a larger number from a smaller one--then you have to "borrow." For example, in the decimal system this is the way you subtract 17 from 42 to get 25:

(1) In the example at the right, we borrow 1 (actually 10) from 4 (actually 40), because we cannot subtract 7 from 2. Then we subtract 1 from 3, not 4, because we had already borrowed from the 4.

$$\begin{array}{r} 42 \\ -17 \\ \hline 25 \end{array}$$

(2) You do the same thing when subtracting using the binary system. But before you start to subtract, learn these three basic rules.

RULES FOR BINARY SUBTRACTION

RULE 1. 0 FROM 0 = 0

RULE 2. 1 FROM 1 = 0

RULE 3. 0 FROM 1 = 1

RULE 4. 1 FROM 0---PUT DOWN 1, AND THEN CHANGE THE NUMBERS IN THE TOP ROW UNTIL YOU CHANGE A 1 TO A 0.

c. Now try an example. Figure 5 shows how to subtract the binary number 0111 from 1010. Follow the step-by-step procedure below:

BINARY SYSTEM		DECIMAL SYSTEM
1010	equals	10
-0111	equals	- 7
0011	equals	3

Figure 5. How to subtract binary numbers.

Step 1. We can't subtract 1 from 0, so we have to borrow 1 from the second place column. Then, following rule 4, put down a 1, and change digits in the top row until you change a 1 to a 0. See part A of figure 5.

```
   0
 1010
-0111
    1
```

Step 2. We still can't subtract 1 from 0, so apply rule 4 again. See part B of figure 5.

```
 010
 1010
-0111
   11
```

Step 3. Now apply rule 2 as in part C of figure 5. 1 - 1 = 0.

```
  010
 1̸0̸1̸0
-0111
 0011
```

Step 4. Now check your answer using addition just as you do in the decimal system.

```
  111
 +011
 1010
```

Try another example. Subtract the binary number 11001 from 110100.

BINARY SYSTEM		DECIMAL SYSTEM
110100	equals	52
-011001	equals	-25
011011	equals	27

Step 1. Apply rule 4:

```
     01
 1101̸0̸0
-011001
      1
```

Step 2. Apply rule 3:

```
     01
 1101̸0̸0
-011001
     11
```

Step 3. Apply rule 1:

```
     01
 1101̸0̸0
-011001
    011
```

Step 4. Apply rule 4:

```
  0  01
 11̸01̸0̸0
-011001
   1011
```

Step 5. Apply rule 4:

```
 00  01
 1̸1̸01̸0̸0
-011001
 011011
```

Step 6. Now check answer by addition:

```
 011001
+011011
 110100
```

---

22. HOW TO MULTIPLY BINARY NUMBERS

a. Multiplication in binary arithmetic is easy. All you have to remember are the following rules:

RULES FOR BINARY MULTIPLICATION

RULE 1.	0 x 0 = 0
RULE 2.	0 x 1 = 0
RULE 3.	1 x 1 = 1

b. However, before you start to multiply, make sure you know how to add binary numbers. Now, multiply the binary number 1101 by 11.

```
BINARY SYSTEM                           DECIMAL SYSTEM

     1101          equals                     13
   x   11          equals                    x 3
     1101                                     39
    1101
   100111
```

c. As you see, multiplication in the binary system is just like multiplication in the decimal system. In fact, it is a lot simpler because you have just two symbols to multiply: 1 and 0. Now, try another example. Multiply the binary number 110111 by 101.

```
BINARY SYSTEM                           DECIMAL SYSTEM

     110111        equals                     55
   x    101        equals                    x 5
     110111                                  275
    000000
   110111
  100010011
```

23. HOW TO DIVIDE BINARY NUMBERS

Before you can divide binary numbers, first you must know how to subtract. So go back and make sure you know the basic rules of binary subtraction. The actual division process is similar to division in the decimal system. Now, try these two simple examples:

```
                 BINARY SYSTEM                  DECIMAL SYSTEM

Example 1:              10                             2
                 111 ) 1110                        7 ) 14
                        111                            14
                          0
```

Example 2:

```
BINARY SYSTEM                     DECIMAL SYSTEM

       11                                3
100 ) 1100                           4 ) 12
      100                                12
       100
       100
```

Here's a more complex problem:

```
BINARY SYSTEM                     DECIMAL SYSTEM

        11                               3
110 ) 10010                          6 ) 18
      110                                18
        110
        110
```

Notice that the binary number 110 is larger than the first three digits (100) in the dividend. Therefore, you must first divide 110 into 1001 as you would do in the decimal system. The divisor, 110, "goes into" the 1001 portion of the dividend once and is set below it as shown. Next, subtract 110 from 1001 to get 11. Bring down the last 0 in the dividend to get 110. Now the divisor, 110, goes into 110 once. Thus, the answer is 11.

Now, try another example:

```
BINARY SYSTEM                     DECIMAL SYSTEM

         11110                           30
111 ) 11010010                       7 ) 210
      111                                21
       1100                               0
        111
        1010                         CHECK              11110
         111                      BY MULTIPLYING:         111
          111                                           11110
          111                                          11110
            0                                         11110
                                                    11010010
```

24. THE OCTAL NUMBERING SYSTEM

a. Another number system also used with computers is the octal number system. The radix (base) of this system is eight and the symbols used are 0, 1, 2, 3, 4, 5, 6, 7. All the rules as used for the binary system hold true for the octal system.

b. Each position of an octal number has a definite value associated with it:

```
2   7   3   5
|   |   |   └──► one's                   =   1
|   |   └──────► eight's                 =   8
|   └──────────► sixty-four's            =  64
└──────────────► five hundred twelve's   = 512
```

(1) The overall value of the number is determined by the symbols which occupy the positions of that number.

(2) We can evaluate the above octal number in the following way:

2 7 3 5

5 x 1	=	5
3 x 8	=	24
7 x 64	=	448
2 x 512	=	1024
		1501

Written in equation form this shows:

$$(2735)_8 = (2 \times 8^3) + (7 \times 8^2) + (3 \times 8^1) + (5 \times 8^0)$$

$$= (1501)_{10}$$

c. This illustrates a method of converting an octal number to a decimal number. To convert a decimal number to an octal number, we perform repetitive division by the radix, eight, and save the remainders. These remainders form the octal number. This is exactly the same procedure we used in converting a decimal number to a binary number.

Example: Convert $(1501)_{10}$ to an octal number.

	R
8 /1501	5
8/ 187	3
8/ 23	7
8/ 2	2
0	

$(2\ 7\ 3\ 5)_8$

d. The principle advantage to the octal number system is its ease of conversion to binary and the ease of conversion of a binary number to octal.

e. To convert an octal number to binary, replace each octal digit with three binary digits (see table IV and use columns 2^0, 2^1, and 2^2).

Example: Convert $(574)_8$ to binary.

$$(574)_8 = (5\text{-}7\text{-}4)_8 = (101\text{-}111\text{-}100)_2 = (101111100)_2$$

f. To convert a binary number to octal you reverse the above process. First, break the binary number into groups of three bits starting from the right. Next, replace each group of three bits with an octal digit.

Example: Convert $(110010111001)_2$ to octal.

$$(110010111001)_2 = (110\text{-}010\text{-}111\text{-}001)_2 = (6\text{-}2\text{-}7\text{-}1)_8 = (6271)_8$$

g. Octal numbers are often used to program binary computers. This eliminates the more complex circuitry which would be required if we used decimal numbers which had to be converted to binary.

25. INPUT

a. The input element consists of all devices that accept, convert, and transport data and instructions into the computer. A computer is unable to understand the printed word. For this reason, the information is converted into some form of language intelligible to the machine. The internal machine language is a series, or train, of electrical currents flowing into the system. This is obtained by alternately turning the electronics flow on and off according to some fixed pattern. This fixed pattern determines in binary digit (bit) code the numbers, letters, or characters which the machine can recognize. The input to the computer translates punched cards, magnetic tape, punched-paper tape, or the key strokes of an operator into the language of the machine. Figure 7 illustrates magnetic tape equipment as input equipment.

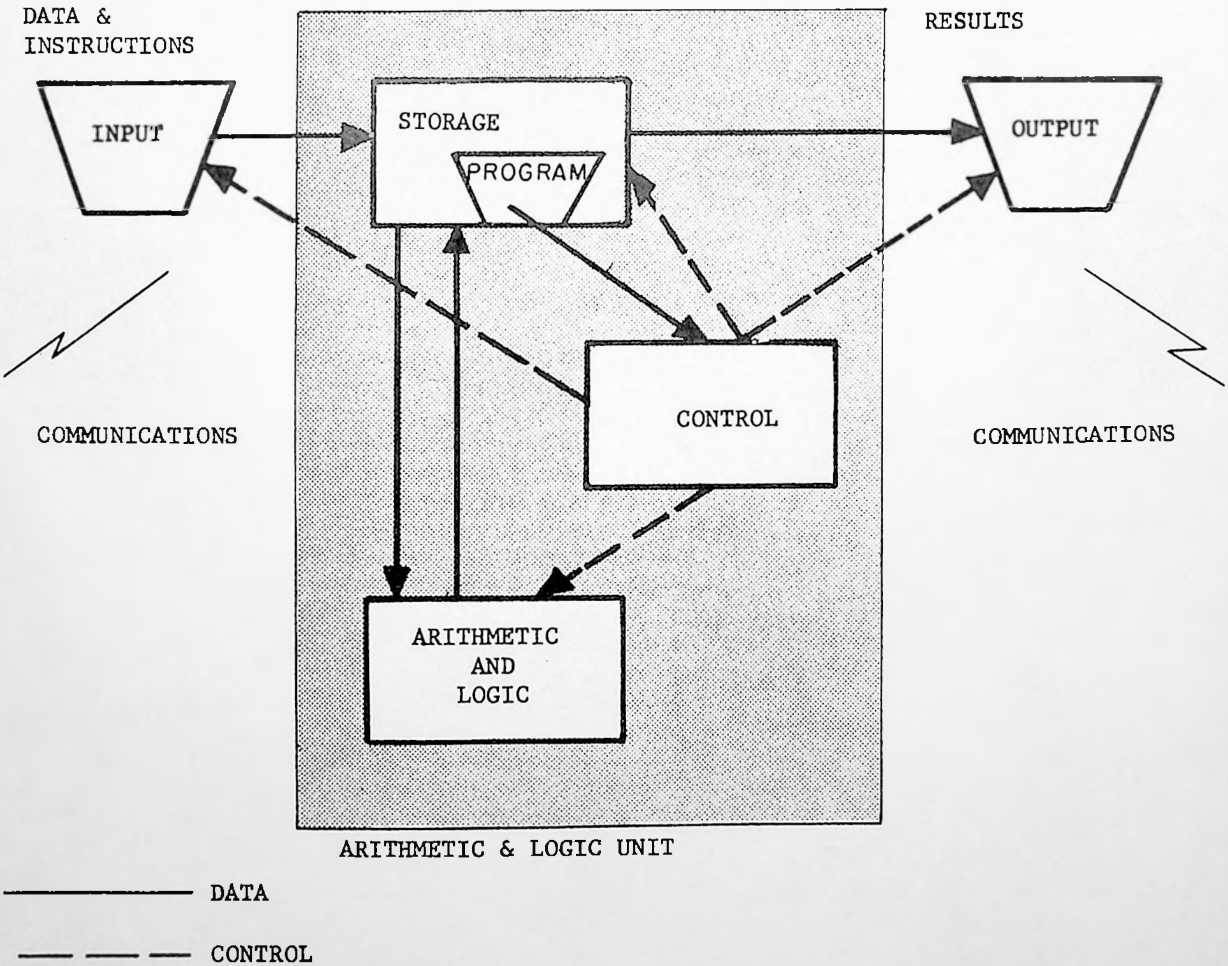
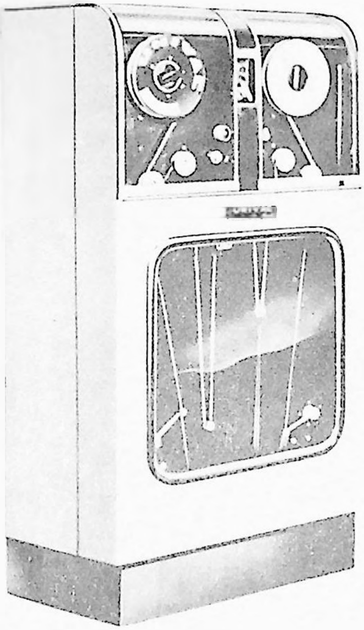
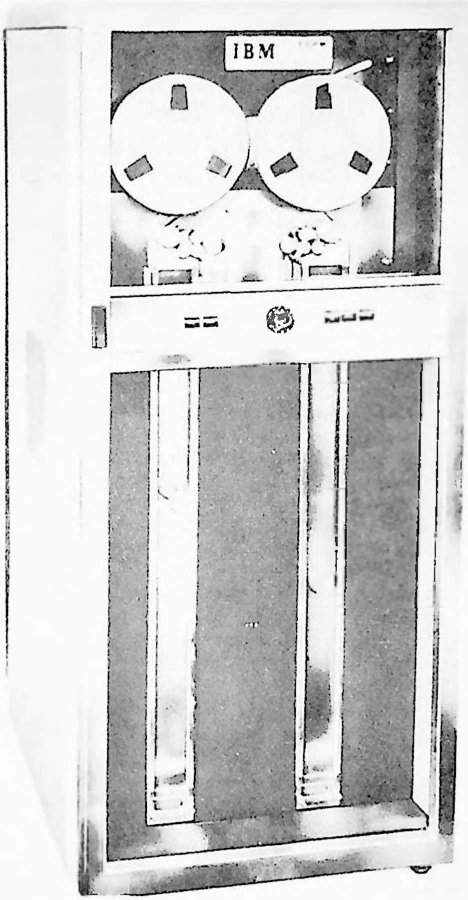


Figure 6. Functional elements of an ADPS.





511-7

Figure 7.
Magnetic tape equipment.

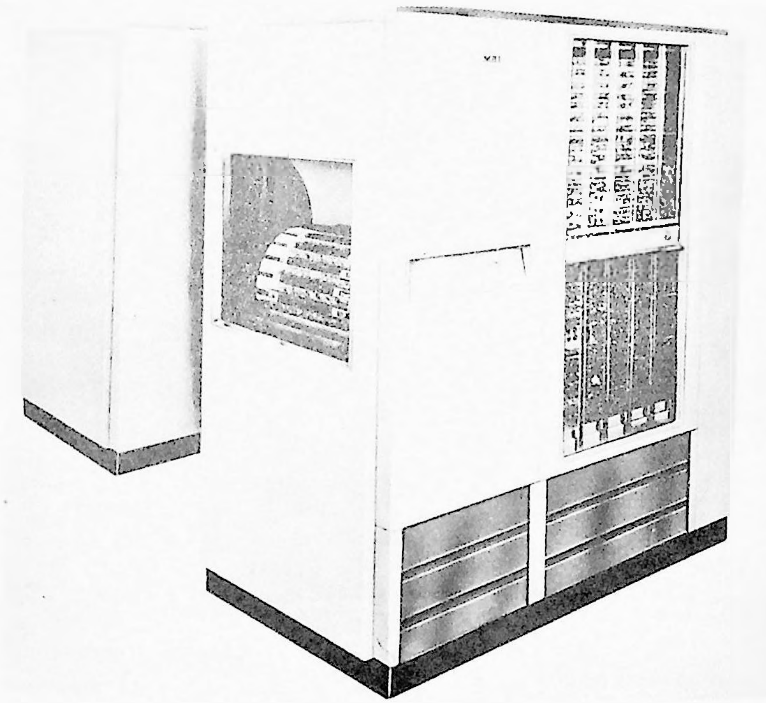
b. Present-day computers can receive information and retain it with no loss, at rates of up to 26 million characters per second. A character is either a letter of the alphabet, or a decimal digit, or some other single mark such as those found on the keyboard of a typewriter. The characters are handled by the computer usually in standard groups called words. Word lengths may be fixed or variable, depending upon the design of the particular computer. Characters may consist of decimal digits only, both letters and digits (alphanumeric or alphameric), or binary digits (bits). An instruction to the machine is expressed as a word or part of a word. Thus, the same set of characters may have a meaning as a number or as an instruction.

26. STORAGE

a. The part of the computer's hardware which holds information is the storage element. It is also referred to as "memory." The memory unit is used to store the data to be worked upon and the instructions for its processing. There are two principal types of memory: internal and external.

b. Internal memory units are those high-speed devices that store data and instructions inside the central processing unit. Information placed in memory is usually in a magnetic form using the binary numbering system. Each binary digit or word must be specifically located in an addressable place. Each instruction that requires the use of stored information must make reference to that exact location. There are many types of internal memories, six of which are mentioned here:

(1) Magnetic drum. A magnetic drum (fig 8) is a metal cylinder, the outer surface of which is coated with a magnetizable material. Data and instructions are stored on the surface of the drum in the form of magnetized binary spots. These spots are a series of parallel tracks. Each track is labeled with a specific address. The drum revolves at high speeds under a series of read-write heads. It is classed as a medium-access speed memory device.

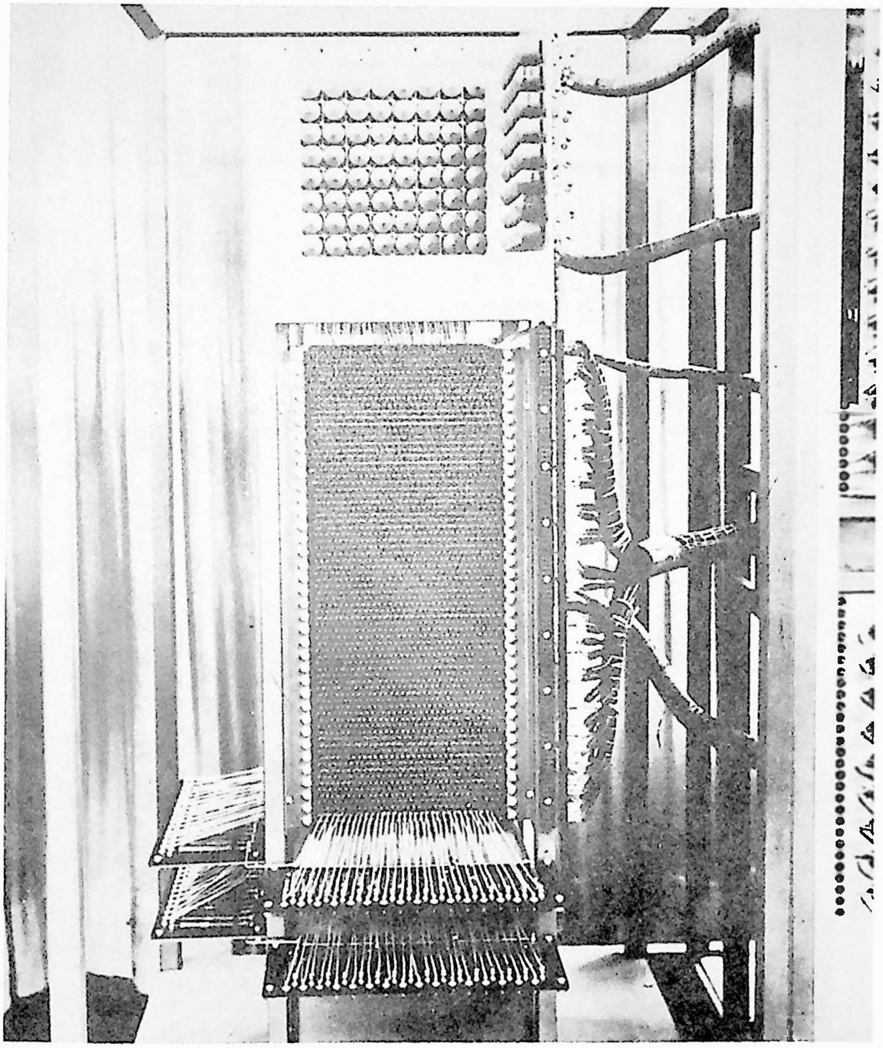


511-8

Figure 8. Magnetic drum storage unit.

(2) Magnetic core. Magnetic core memory is becoming the most popular internal storage device (fig 9) because of its high-speed access, ease of maintenance, and accuracy. The magnetic cores are tiny doughnut-shaped rings of ferromagnetic material. Each is about 1/16th of an inch in diameter, or about twice the size of the period at the end of this sentence. These tiny cores are strung on frames in a matrix fashion, with one core for each binary bit. Usually, six cores are needed to denote a decimal number or alphabetical letter.

(3) Magnetic disk. Magnetic disk storage is a series of metallic disks stacked and arranged in much the same manner as phonograph records in a juke box (fig 10). Information is recorded in magnetic binary-digit form on the disk. A moving selector arm can locate a specified disk, a certain track on that disk, and finally, a specific part of the track for either recording or reading information. A magnetic disk storage unit usually consists of a number of disks, each side or face of which is used. Each disk face contains a number of tracks. Each track holds a number of digits arranged into words. The magnetic disk is often called a random-access file storage device.

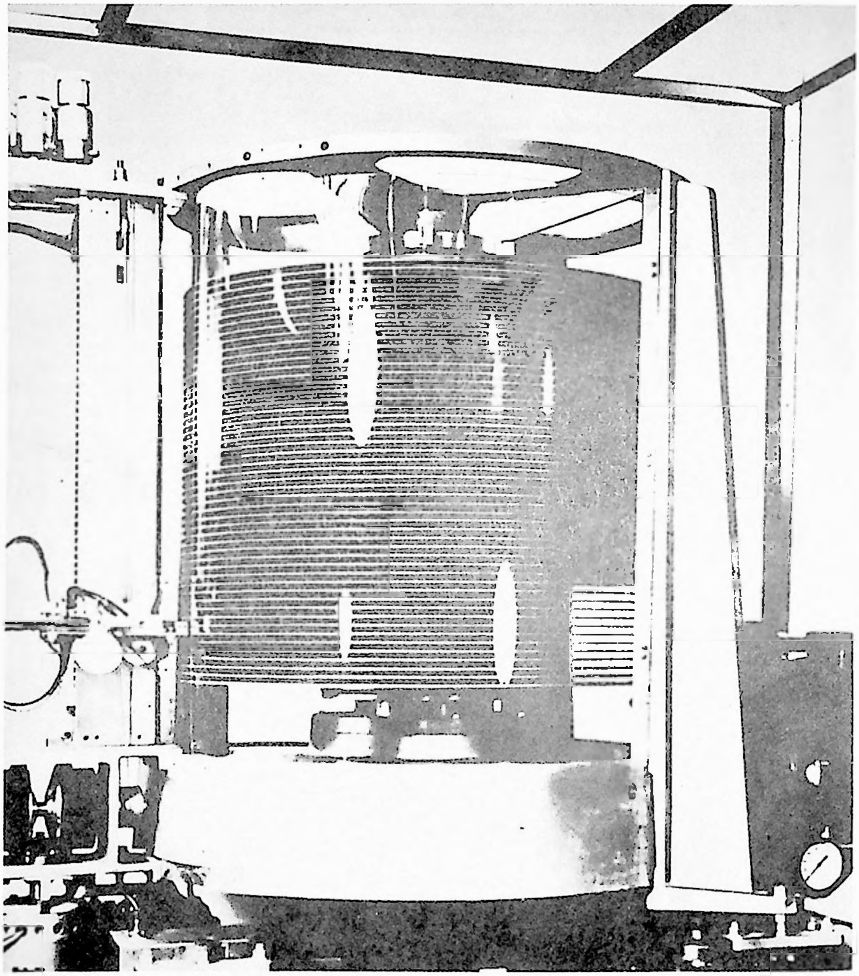


511-9

Figure 9. Magnetic core storage unit.

(4) Electrostatic storage device. One of the earlier forms of memory was the electrostatic storage tube (fig 11) which was actually a cathode ray tube. A constant source of power was required to constantly regenerate the binary symbol images on the tube face. Its greatest drawback was the loss of data in the event of loss of power.

(5) Acoustic delay line. Another early form of internal storage is the acoustic (sonic) delay line. In this system, electrical impulses are converted into sound waves, are delayed by the delay line, and then are reconverted to electrical pulses at the output (fig 12). By feeding the output back to the input, the pulse train moves continuously (recirculated) around the delay loop. The



511-10

Figure 10. Magnetic disk storage unit.

principle used in this system is based on the fact that sound waves take a certain amount of time to travel through the material used as the transmission medium. Any loss of power, however, meant the loss of data. The early UNIVAC computer used columns of mercury as the delay medium. Quartz crystals converted the electrical pulses into sound energy, and reconverted the sound back to electrical energy. Newer types of delay lines have been developed. One of these is the magnetostrictive sonic delay line. Magnetostriction is the term used to denote the change in dimension of certain metals, such as nickel, that takes place when subjected to a magnetic field. This type of delay line uses acoustic delay in metal wire. Transducers are used at both the input and output to do the job of converting electrical pulses into sound waves, and vice versa. As with the mercury storage delay line, recirculation of the data pulses is necessary as there is no place to actually "store" the pulses. A typical delay line is able to dynamically "store" 10,000 bits.

(6) Thin film. One recently developed memory device comes in the form of thin magnetic and cryogenic (very low temperature) film. This device, about the size of a postage stamp, has 19 layers of superconductive metals and insulating materials sandwiched together make up 40 memory cells. Each cell can store one bit of information, have a logical operation, such as addition or division performed on it, and feed out the results. The most significant characteristic of this type of memory is the extreme access speed it possesses. Data can be retrieved from thin film at speeds measured in nanoseconds (billionths of a second).

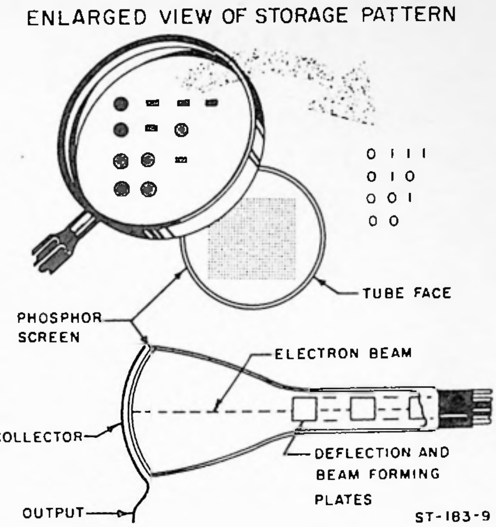


Figure 11. Electrostatic storage tube.

c. External memory units are external to the computer and are designed for the storage of large volumes of data, such as master files. Directly opposite in nature from internal storage, external storage features large capacity and long access time. There are several types of external storage. Three types are mentioned below:

(1) Punched cards.

(a) Punched cards are of standard size with space for 80 or 90 columns across the card. The IBM card (fig 13a) has 80 columns, with 12 punching positions in each column used to represent different characters. The Remington Rand card (fig 13b) has 90 columns arranged in two horizontal rows of 45 columns each.

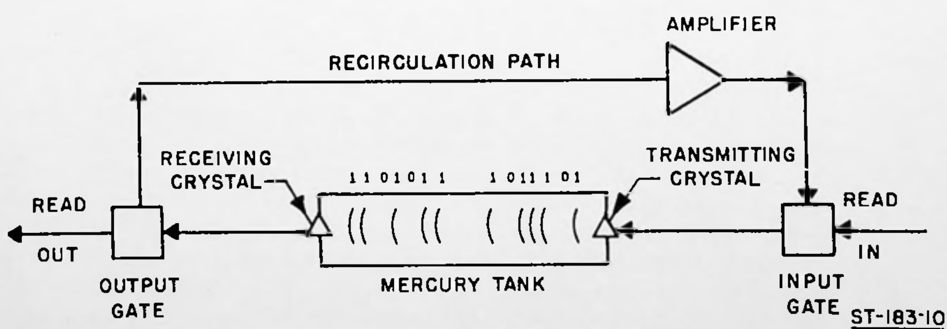


Figure 12. Mercury storage delay line.

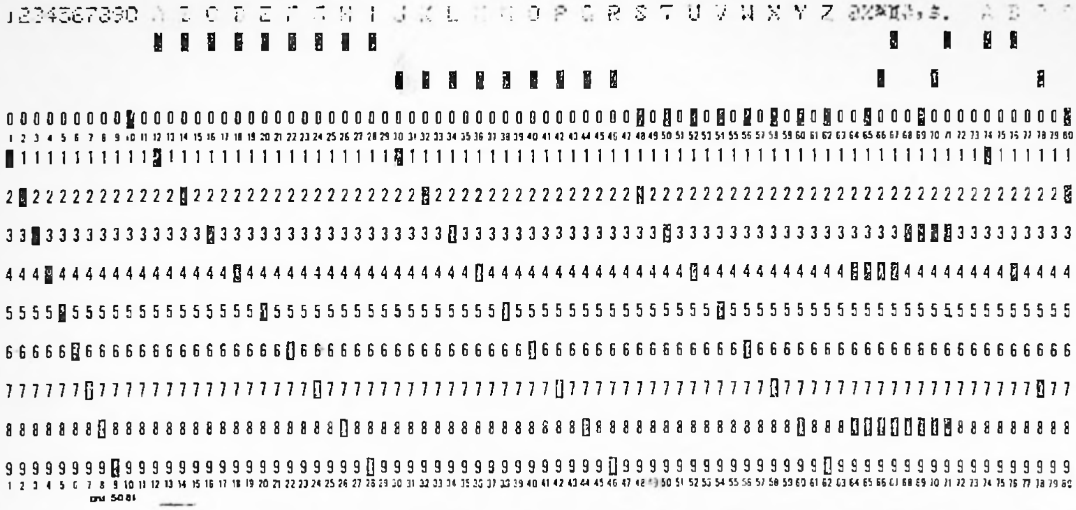


Figure 13a. IBM card. 511-13a

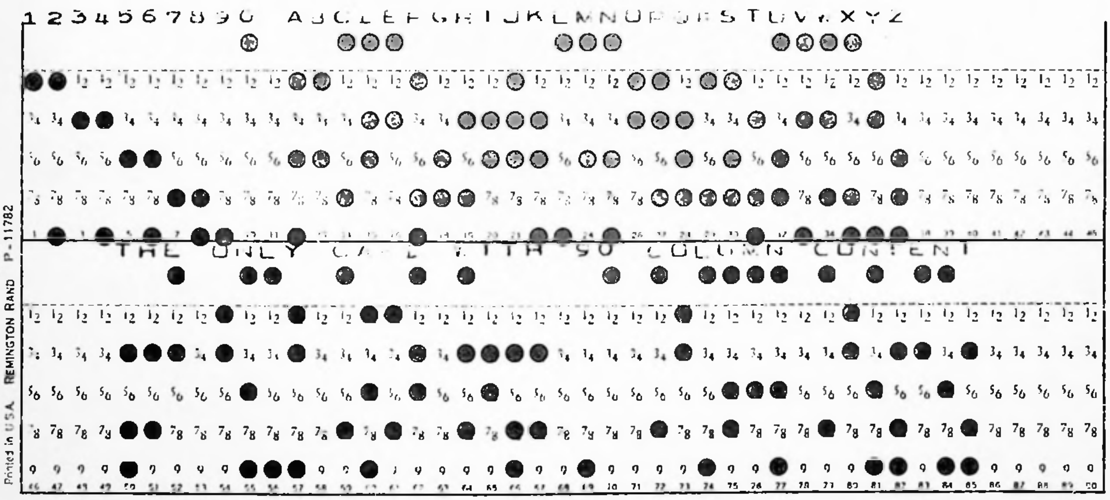
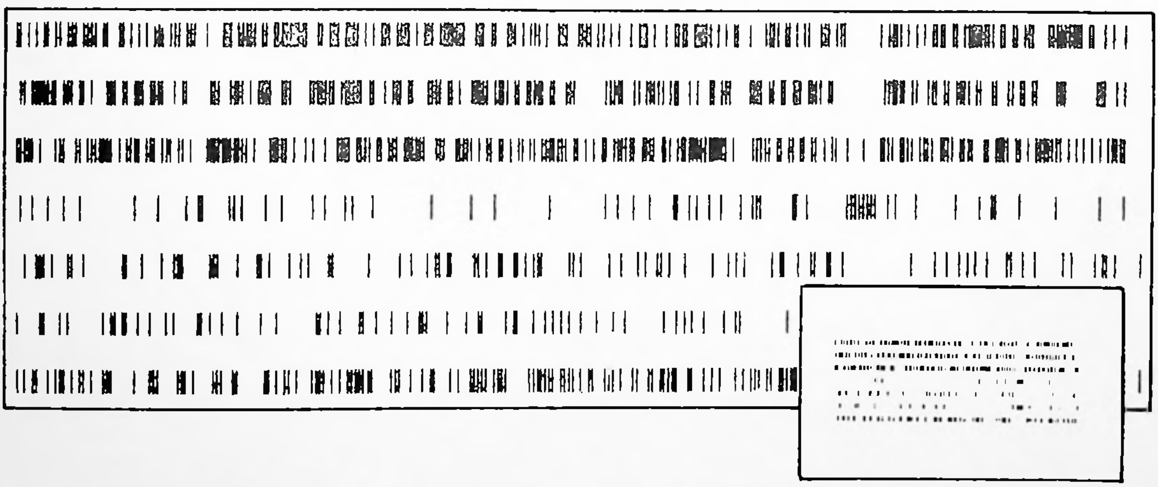


Figure 13b. Remington Rand card. 511-13b

(b) Using punched cards to put data into the machine has several advantages. Cards can be handled, sorted, corrected, and manipulated manually. Cards are also used as source documents or as records. There are several disadvantages to the use of cards also. Among these are the limitations imposed by the physical characteristics of the card itself: normally only 80 or 90 characters can be recorded on each individual card; card files tend to become bulky; and an inventory of blank cards must be maintained.

(2) Punched paper tape. Punched paper tape has a variable record length. Although information is recorded in columnar fashion, it is not limited to the 80 or 90 columns of the punched card. The different channel codes used give paper tape a great versatility. A main disadvantage in the use of paper tape is in the difficulty of reclassifying data without first changing the data to some form of unit record, such as punched cards. However, punched paper tape can provide a large amount of stored information.

(3) Magnetic tape. Magnetic tape is a high-speed method for either input or output. More than 20 million characters can be stored (800 characters to the inch) on a single reel of tape. This is the equivalent of the information contained in a stack of punched cards over 150 feet high. Data may be written or read at speeds up to 240,000 characters per second. The tape itself usually is composed of a plastic base, coated with a metallic oxide surface. Magnetic spots are magnetized on this surface to represent data. Figure 14 shows an enlargement of magnetized spots representing a magnetic tape record. The insert shows an approximation of the width of the tape, and the length represents the data from an entire 80-character card. A very large computer such as the IBM 7030 STRETCH may have access to as many as 256 reels of magnetic tape on magnetic tape handling devices. Each reel may contain up to 20 million words. These words are available on call from the central processing unit of the computer. Magnetic tape is a sequential-access storage device.



511-14

Figure 14. Magnetized magnetic tape.

27. ARITHMETIC AND LOGIC

a. The part of the computer that performs all the calculating or mathematical work is the arithmetic and logic unit, which is considered to be the heart of the system. This unit has only a small memory, usually three but not more than five words. Data is manipulated within the unit by computation circuits known as adders, counters, registers, and accumulators. Among the manipulations possible are addition, subtraction, multiplication, division, comparison, and selection. For instance, it is possible to set up a number from the main storage in a register, to bring in another number from memory, to manipulate the two factors, and to have the results available for replacement into the original record. All of this is directed by the stored instruction program within the machine.

b. Most computers have built-in instructions such as add, shift, read, and compare. In addition to these built-in programs, manufacturers usually provide a library of programs for their equipment.

c. Simplified languages for instructing computers have been developed. One such program designed specifically for the IBM 650 computer is "SOAP" (symbolic optimum assembly program). Using SOAP, the programer can program a problem in terms of simple elementary instructions. These instructions are names with high mnemonic value rather than numerical designations. They are given to storage locations and these addresses are referred to by these names. Thus, TAXABLE INCOME might be stored in location TAXIN, a mnemonic. The principal advantage of an assembly program is that it allows a programer to write a program in modified English language. It also allows a non-programer to understand and perform a desk check of the program without wading through a profusion of numerical designations.

28. CONTROL

The control element directs the computer in performing its operations. It carries out the instructions given to the machine, and executes the sequence or program of instructions. The control unit consists basically of a register which contains the current instruction for the machine at each cycle of operation. It instructs the machine as to what register to take information from, what register to put information into, and what register contains the next instruction to be executed. The flow of instructions into the machine is produced by the program. Computers today can handle two million instructions per second. The control may be either internal or external, or a combination of the two.

a. Internal control facilities interpret machine instructions and activate proper circuits. The circuitry which controls the sequence of operations is also included in this section. The typical internal control section contains two main units: the instruction register and the program counter. The instruction register examines and interprets the operational part of the instruction, and the program counter keeps track of the program sequence. Thus, the next instruction location (address) is set up in the program counter while the system is completing the previous step.

b. External controls are the manual functions performed at the operator's console. Through a series of switches, buttons, and lights, the operator is able to control and supervise the various operational areas of the machine. The operator can, by means of the control console, exercise manual control of the machine, determine the status of machine circuits, indicate and allow for correction of errors, display machine or program error conditions, display memory, enter information into the system, or diagnose machine failures.

29. OUTPUT

a. The output is similar to the input except that it works in the opposite direction. Output may be defined as being information that is modified or updated. That part of the machine that puts out information is called the output device. Output may be in either a readable or nonreadable form. Information that is finished and readable appears as printed copy. Nonreadable output may take on many forms. The most frequently used types are the magnetic tape and punched card.

b. The output of a computer varies according to the capacity of the equipment receiving the information. A computer can record on magnetic tape at the rate of up to 240,000 characters per second. The computer can also control a paper tape punch which can punch paper tape at the rate of 1800 characters per second, or a card punch which will punch about 30 standard 80-column cards per second, or a high-speed line printer which will print 17 lines of 80-120 characters per second.

c. The peripheral equipment is rather slow as compared to the speed of the computer. For efficient use of the computer's tremendous calculating speed, devices called buffers are used. A buffer, as mentioned earlier, is a storage device which is able to receive information then release the information at the proper speed for the peripheral equipment.

30. COMMUNICATION LINK

The final essential element of the automatic data processing system is its supporting communication linkages.

a. To be suitable for large-scale operations, such as those of the Army and any large industry, a data processing system must have secure high-speed communications integrated with the capabilities of the computer. Without this communication system, the computer could well be an expensive tool that will perform at a fraction of its capabilities.

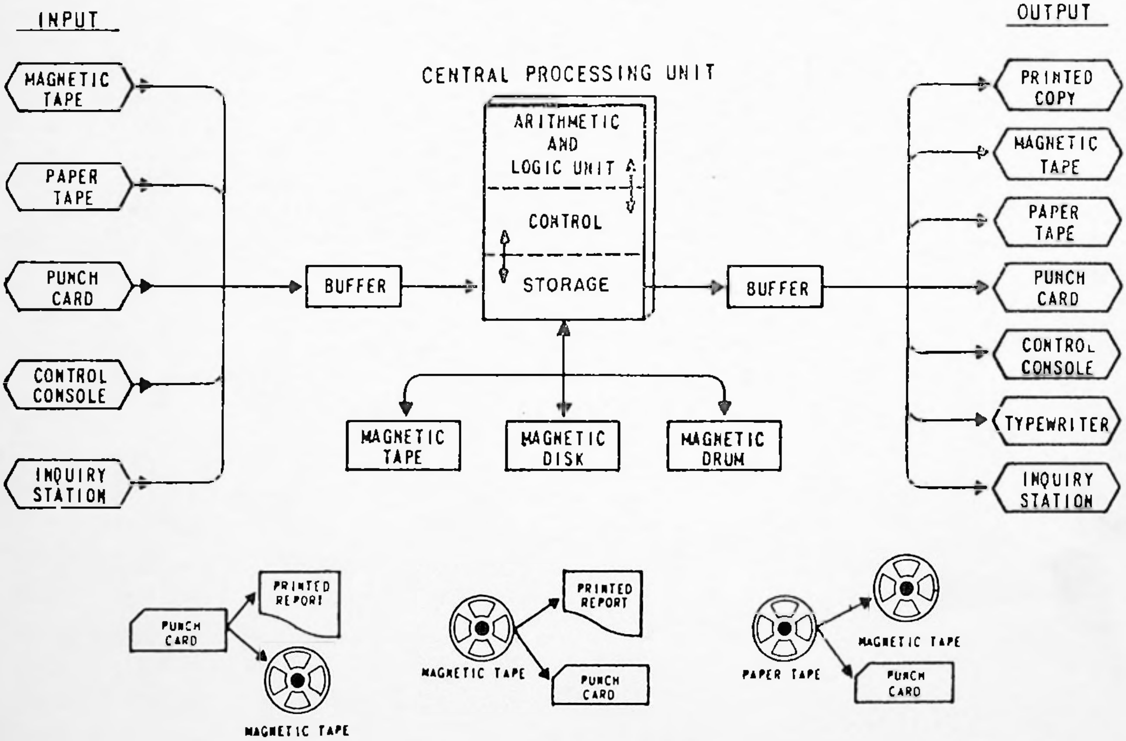
b. The fact that automation is being extended through the communication system emphasizes the need for an intimate relationship between computer and communication procedures. This relationship indicates the need for an integrated data processing-communication system.

c. The sources for data for the machine are the units at posts, camps, stations, and headquarters in the field throughout the world. The communication system serving these units must deliver data to its destination in the same format and form in which it was obtained from the originator. The Army cannot economically afford a separate communication system for each of the various communication modes now in use.

d. The subject of data communications, because of its importance, will be treated as a separate subject in IB 511 (Part II), Section XXVI.

31. GENERAL

a. The six functional elements of an automatic data processing system (input, memory, arithmetic and logic, control, output, and communications) were briefly described in the preceding section. It is our purpose to further describe all these elements, except communications, and to familiarize you with their principles and theory of operations. Emphasis will be placed on the inner workings of data storage, and the arithmetic and logic unit of the central processor. Figure 15 shows a composite ADP system.



511-15

Figure 15. Composite ADPS schematic.

b. How can we get a machine to "understand"--to do what we want it to do? The theme that is generally accepted is that we must use a language that it understands as the input media. This language may consist of the presence or the absence of holes punched in cards and paper tape, or the magnetizing of spots on magnetic tape. These are considered to be the three principal input media, each with their own peculiar code form, that are used to make the computer and its peripheral equipment do our bidding. On the other hand, the machine must furnish, as an output, processed data that is understandable to us.

c. Input and output devices are necessary components in automatic data processing. Just what devices are used depends upon the form the data is in and the form the computer will accept. Data may be in the form of punched cards, punched paper tape, and magnetic tape. Some computers do not accept all these sources. When data is in a form which cannot be accepted directly by a computer, it must be converted to a form which is acceptable by off-line processing. Computer systems may include card punches, card readers, paper tape units, magnetic tape units, printers, and other types of machines used for the processing of data outside the computer itself.

d. Since the punched card--the forerunner of ADP--is widely used in ADP applications, it will be treated in detail as part of this section.

32. THE PUNCHED CARD

The basic element of any punched card machine system (PCMS) is a card of uniform size and shape into which holes are punched. The purpose of punching holes into a card is to record selected information about a particular transaction or event. The card is really a tabulating card, but is better known as a punched card. The holes are punched into predetermined positions in each card, for the holes determine the meaning of the information. The punching of the card for original entries is the only completely manual operation in any punched card procedure. The punched card then becomes a permanent record that may be read, processed, and recorded by punched card machines.

a. Types of Punched Cards. It could be said that there are about as many types of punched card designs as there are businesses to use them. Each business, by its nature, requires detailed information on different items. However, the punched cards in use can generally be classified as one of four basic types.

(1) Transcript cards. An operator reads the information that is written on a document, and by using the punched card process, punches the data into the card. In brief, he makes a copy of the original document.

(2) Dual cards. A dual card is one that provides space for manually recording information and for punching this information on the same card. Thus, the dual card serves as an original record and as a means for actuating punched card equipment.

(3) Mark sense cards. A mark sense card is a specially prepared card which can be automatically punched in a card reproducer after it has been marked by an electrographic pencil. The appropriate marks are made on the card; and when it is processed by the reproducer, punched holes are made because the reproducer is activated by sensing the pencil marks recorded on the card.

(4) Summary card. A summary card is a form of transcript card. Its purpose is to record total information obtained from a tabulation of groups of cards. Whenever the card is punched for a total which represents the sum of more than one card, the card so punched is a summary card. This card is usually made as a by-product during the preparation of a report. The purpose of a summary card is to reduce card volume for subsequent reports.

b. Differences in Cards. Speed of performance is the essence of the punched card system. There are three methods used to distinguish between cards of different applications, regardless of their card design. These methods are corner cut, color, and significant punching.

(1) Corner cut. One of the corners of the tabulating cards is generally cut off. The corner cut serves the purpose of distinguishing between types of cards. It also aids machine operators to determine that all cards are stacked properly for correct feeding into the machine.

(2) Color. Colored cards enable an operator to visually detect the type of card being used, as well as any cards from another group which may have been included accidently. Punched cards may be obtained in several different solid colors or with various colored stripes.

(3) Significant punching. Another method of identifying cards is to punch an identifying position in a certain column of the cards. This punched hole provides a means of selecting a given type of card manually and visually from a file. Another way of automatically selecting cards with a significant punch is with a sorter.

c. Handling of Cards. In order to prolong the usefulness of the punched card, and to eliminate possible machine trouble, cards should be:

(1) Properly "jogged" to attain alignment, and "fanned" to remove static electricity before they are placed in the punched card machines.

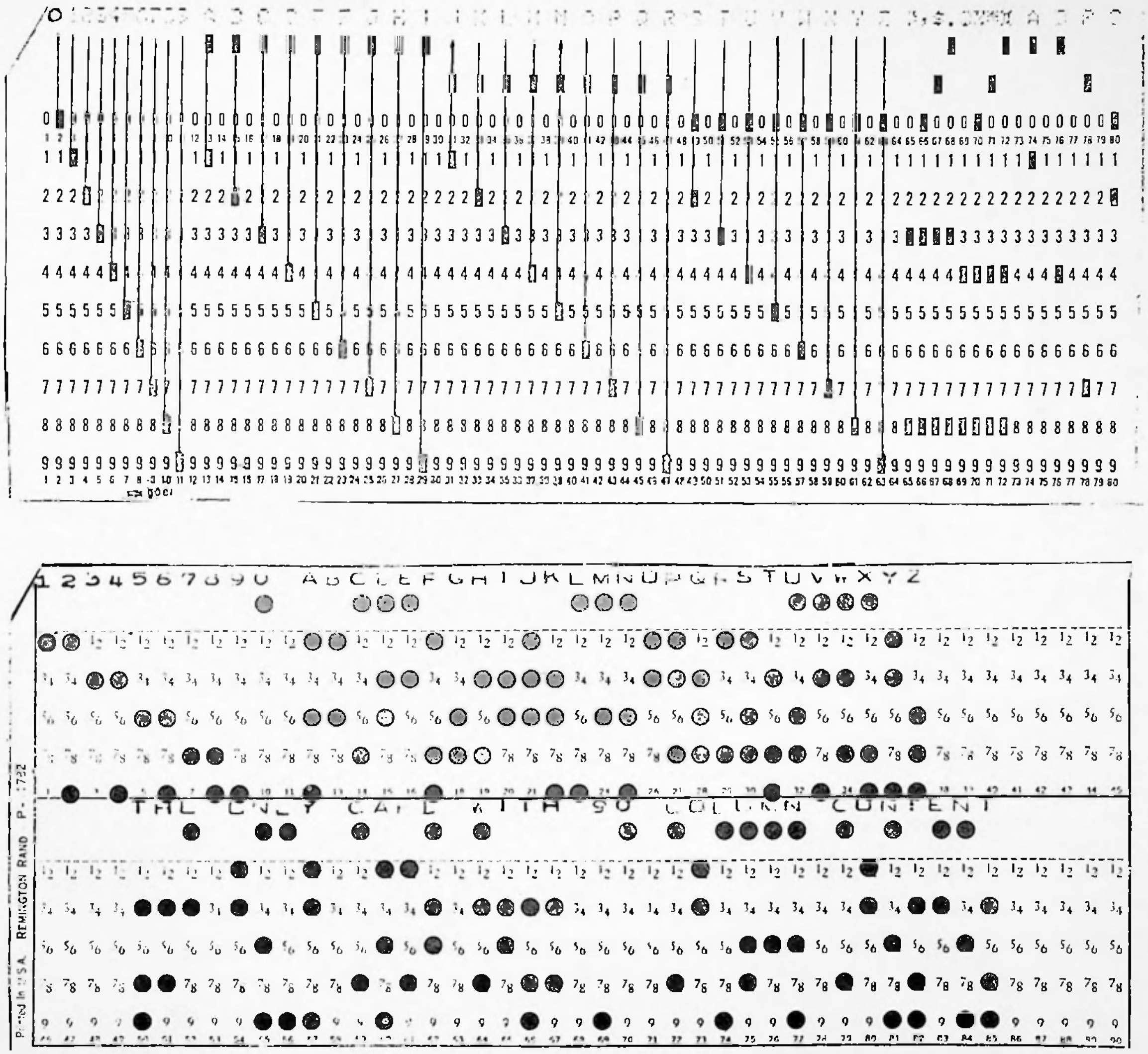
(2) Stored where temperature and humidity as recommended by the manufacturer are kept constant.

(3) Properly blocked and stored in filing cabinets until ready for use.

33. PUNCHED CARD DESIGN

Let us examine two major types of cards in detail (fig 16).

a. The standard IBM card has 80 vertical columns into which holes may be punched by the card (key) punch machine. These holes can represent the digits 0-9, all alphabetical characters A-Z, and several special characters. There are 12 vertical punching positions in each column. Digits are recorded in a card by punching a single hole in a given column in the position that represents the digits. Alphabetical information is recorded in the card by a code. Each alphabetical character is made up of two punches, a numerical punch (1-9) and a zone punch. The zone positions are located at the top edge of the card. Two of the zone positions (11 and 12) are unnumbered because this area is used for the printing of headings. The 12 zone is at the extreme top edge of the card. The 0 zone is numbered. The 0 position also serves the purpose of the numerical zero (0). The 11 zone is between the 12 and the 0 zones. Cards are often referred to by the 12 edge or the 9 edge. These edges are the top (12) and the bottom (9) of the card. Some machines are made so that, to do the operations properly, the card must be fed in with the 9 edge first. Others take the 12 edge first. They are fed face down in most machines. Cards are punched according to a code.



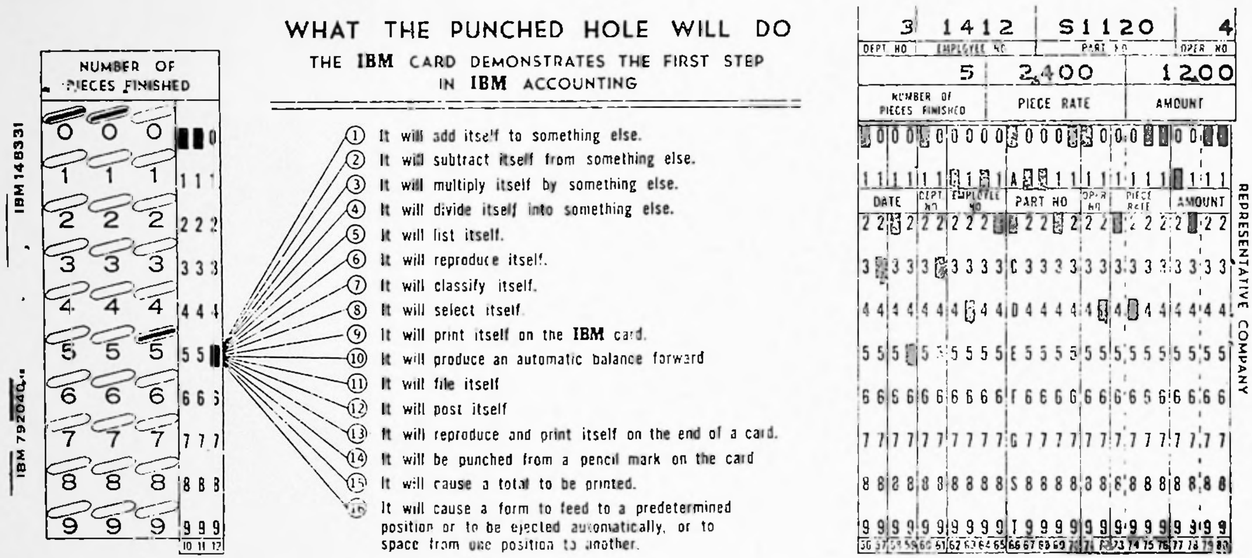
511-16

Figure 16. Representative cards showing digits and alphabet.
(Top--IBM; bottom--Remington Rand)

b. The Remington Rand card has 90 columns arranged in two horizontal rows of 45 columns each. One row of columns is across the top half of the card, numbered from 1-45. The bottom half contains the columns numbered from 46 to 90. There are six punching positions for each character. This system is more complicated and not as regular as the IBM card. The numeric system follows a pattern. Two punches are used for even numbers and one punch for the odd numbers. There is no discernible pattern for alphabetical characters.

34. PUNCHED CARD PROCESSING

The punched holes that a key punch operator puts into a card allow the other punched card machines to perform their various operations. The card punch machine is used to transcribe the information from the source document into punched holes. Without holes, the card is useless. A card, then, can be thought of as a device to hold the holes (fig 17).

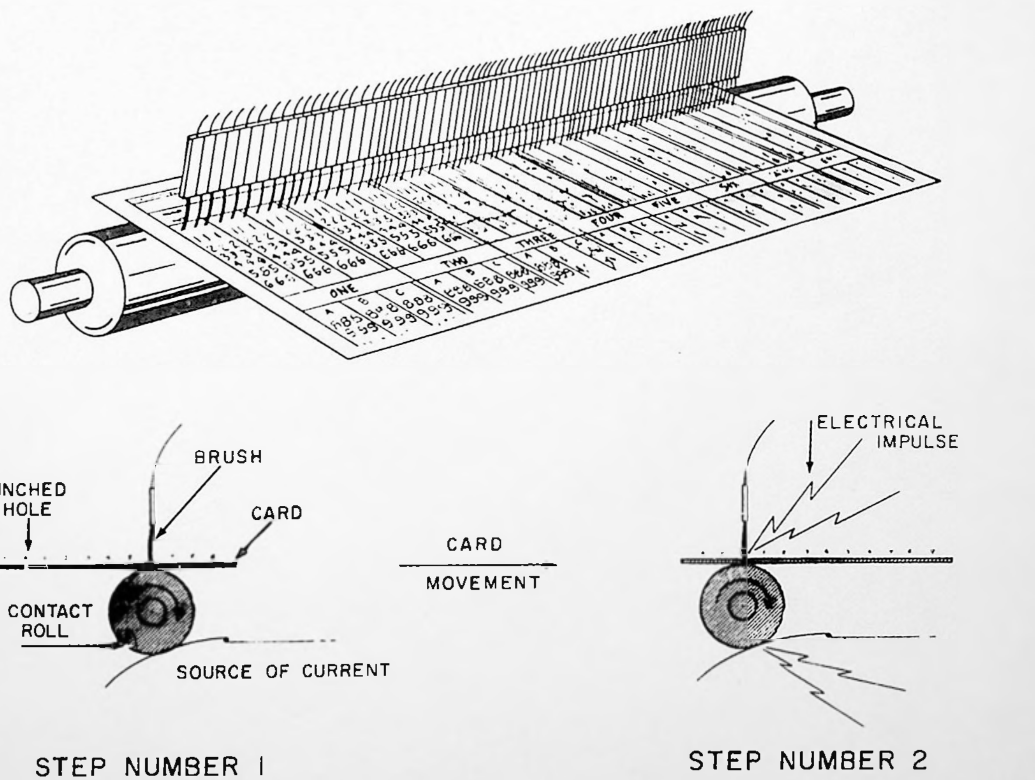


511-17

Figure 17. What the punched hole will do (IBM).

a. Most punched card machines operate by direct electrical impulses. Almost all operations are controlled by a wired control panel. Electrical current is allowed to enter the machine and is directed to the various machine elements by this control panel. We will not go into the wiring of a control panel. It is an art in itself, and is beyond the scope of this instruction book.

b. Let's see what electricity has to do with the punched holes. Look at figure 18. Here we have an electrically charged metal-contact cylinder. Above the roll is a row of contacts or brushes--in fact, 80 of them to match the 80 columns of the card. Without the card, which is a nonconductor of electricity, there is current flow from the contact roll through the brushes. If we let a card move between the roll and the brushes, there is no current flow. What happens if there are some small holes punched in the card? As the card is moved over the cylinder, the brushes make contact through the holes. Current passes into the brush and on to the various parts of the machine to represent numbers and characters. The current flow will continue until the contact is broken by the unpunched portion of the card. Thus, each machine that processes cards works on the principle of a reading brush sensing a hole punched in a card and picking up an electrical impulse which is diverted to perform some function.



511-18

Figure 18. Reading a card.

c. What is there about the impulse that makes the machine recognize what the operator has punched on the card? Certainly one electrical impulse is no different from another. The answer lies in the "timing" of the impulse that occurs during a card cycle. A card cycle is usually the time required for a card to be completely read at one station and to pass to another station. The reading cycle begins as the card is fed into the machine. As the card reaches the reading brush at the 8 position in the card, for example, a certain portion of the cycle has elapsed. This is generally referred to as "8 time." Any electrical impulse received at this 8 time will be known to the machine as an 8, and it will be treated as such in all machine uses of it. The machine recognizes which digit has been punched in the card by the amount of time which has elapsed from the moment the leading edge of the card passes under the brush until an impulse is available through a punched hole. Timing also enables the machine to recognize two or more holes as characters.

d. In both input and output operations, data is processed on a row-by-row basis. The reading brushes are sometimes referred to as the "eyes" of the machine. The various punched card machines have different brush arrangements. The sorter, for example, has the simplest method of reading a card. It is capable of reading only one column at a time. The one reading brush is moved manually to the designated column to be read.

e. Reading brushes are not the only method of sensing a punched hole. Remington Rand's machines read by a method of steel pins, which sense the holes in the card.

35. GENERAL

The most common method of converting source data into the punched card is by manual means. Punched cards can be used and manipulated by a variety of punched card machines (PCM). Among these machines are the card punch, the verifier, the interpreter, the sorter, the collator, the reproducer, and the accounting machine (fig 19). Since the preponderance of PCM equipment in the field is of IBM manufacture, the descriptions in this section are based on such equipment.

36. THE CARD PUNCH

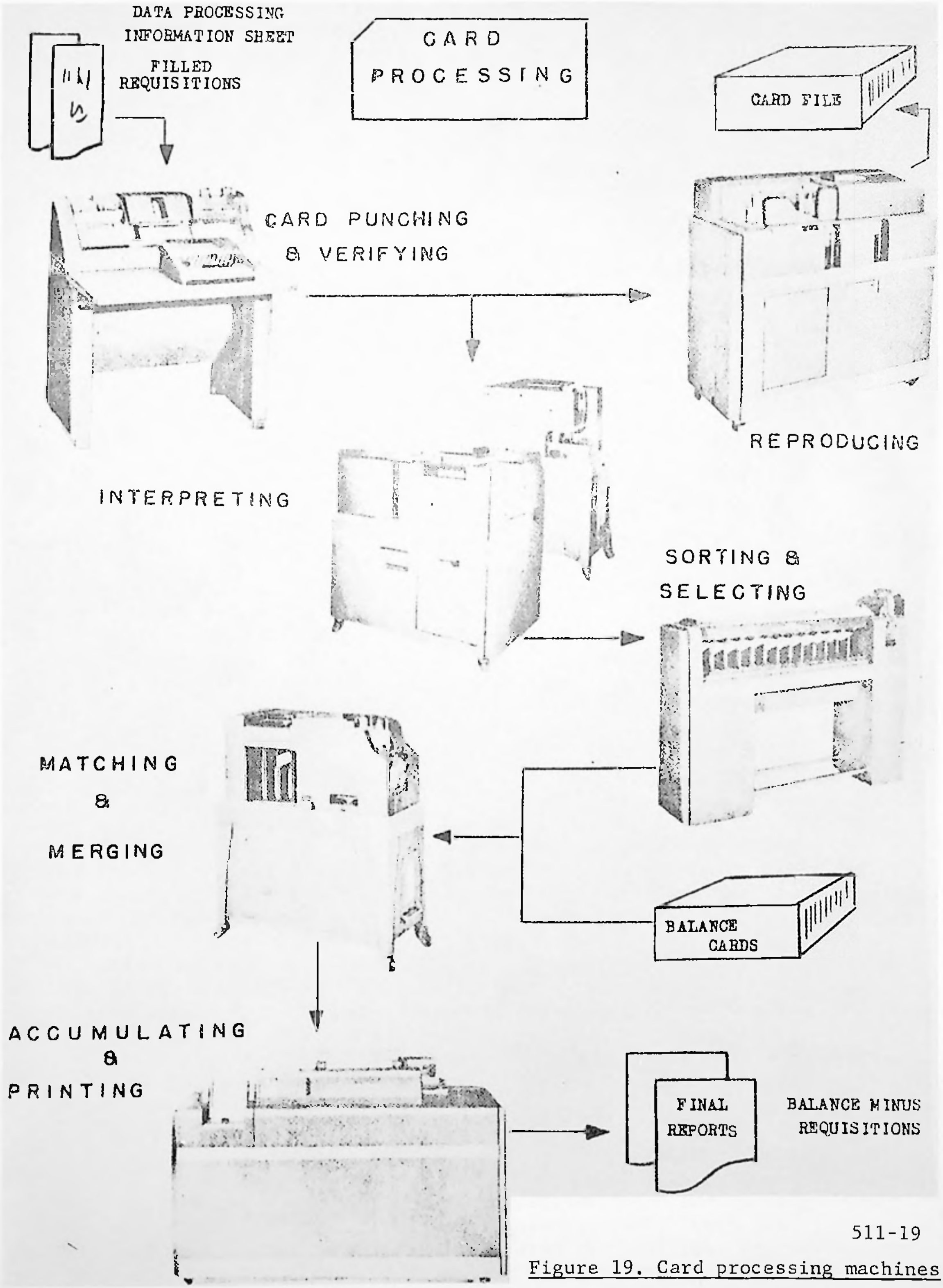
The card punch is the machine that records source data into cards. A keyboard similar to that of a typewriter is operated to activate the punching mechanisms. Holes are cut by columns. As each column is punched to correspond with the key that is depressed, the card is automatically advanced to the next column. As the card moves from right to left through the punching station, the columns are punched from left to right. Blank cards to be punched are placed in the card hopper. The cards are fed from the hopper to the card bed automatically or by depression of the feed key. In one type of machine the first two cards to be punched must be fed by key depression, but all other cards can be fed automatically, under control of a switch. After the card is punched, it passes through the reading station on the card punch machine. Here, it is read as the next card to be punched passes through the punching station. The two cards are moved at the same time, column by column, and the information to be duplicated is transferred from the card being read to the card being punched. Punching from one card to another can be controlled field by field, so that only the desired information is duplicated. A field is a column or a group of columns set aside for specific information, such as a name. After each card passes the reading station, it is fed into the card stacker which places the cards in their original sequence.

37. THE CARD VERIFIER

Card verifying is simply a means of checking the accuracy of the original key punching. The card verifier itself is similar in appearance to the card punch. It has a verifying station instead of a punching station. A second operator verifies the original punching by operating the keys of the verifier while reading from the same source document. The verifier will detect an error when there is a discrepancy between the key depressed and the punched holes in the card column. When an error is detected, an error light turns on and the keyboard becomes inoperative. The card column is notched as an error and the card skips to the next column. Depressing the error release key frees the keyboard. When a card has been verified to be correct, a notch is cut in the right end of the card between the 0 and 1 positions. If there is an error in the punching of a particular column of a card, a notch is cut directly above that column. New cards, of course, must be prepared to replace those with errors.

38. THE CARD INTERPRETER

The purpose of the card interpreter is to print any desired information which is in the card. This printing is on the face of the card across the top above the 12 position. If more than one line of printing is required, the second line of print is placed between the 12 and 11 positions. This



511-19

Figure 19. Card processing machines.

printing is an aid in the visual verification of the data that is punched on the card. Features differ on various makes of interpreters, but in general the operations are similar. Of the machines described so far, the interpreter is the first which uses a wired control panel to direct its operations. Usually, the printing mechanism consists of type bars or print wheels containing 10 numerical, 26 alphabetical, and several special characters. Sixty characters can be printed across a card in one pass through the machine. If more than 60 columns are to be interpreted, the cards must be run through a second time, with the information being printed on the second printing line. A second pass requires the use of two control panels.

39. THE CARD SORTER

a. Arranging a deck of punched cards into any desired sequence by hand is a time-consuming and tedious operation. The sorter does this mechanically in a fraction of the time required to do it manually. The sorter can arrange a deck of cards in either a numerical or alphabetical sequence. However, it is capable of sorting only one column at a time.

b. The operating principle of a sorter is basically the same for the various models. The cards are fed horizontally from the card hopper, passing over a contact roll and under the reading brush which is positioned at the selected column. When the brush reads a punched hole, it makes contact with the roll, thus completing an electrical circuit. An electrical impulse is sent through an analyzer network to a sort magnet. This is selective sorting and with this system, cards are not directed to a pocket until all the punches in a column have been analyzed. After the column has been read, the sort magnet is energized, pulling down the appropriate chute blade, which allows the card to fall into the selected pocket. There are 13 pockets in the sorter, one for each punching position and one for rejected cards. A card is rejected if no hole is punched in the column being sorted, or if there is an error in that column. Normally, two sorts are required to sort alphabetically, while numerical sorting requires only one pass.

40. THE CARD COLLATOR

One of the greatest problems in any manual system is the withdrawing and filing of cards according to a predetermined pattern. The sorter can merge two groups of cards that are in no particular sequence, however, when one or both of these groups are already in sequence, the use of the sorter results in a considerable loss of time. Advantage cannot be taken of the sequence of one or both files, and a complete sorting operation must be performed. The collator improves this operation by merging two groups of presorted cards into one file without sorting. The collator performs many operations. It is sometimes referred to as an automatic file clerk. Some of the more basic functions and applications of the collator are listed below:

a. Sequence Checking. This is an operation whereby the present sequence of a file of cards is checked.

b. Merging. Merging is the combining of two sets of punched cards into one set of a given sequence.

c. Matching. Matching is a checking function used to check or compare cards of one group with similar cards of another group.

41. THE CARD REPRODUCING PUNCH

a. One characteristic of manual recording is monotonous repetition. Identical data must be punched into many cards. For many reasons a duplicate deck must be made. The reproducing punch is the machine that automatically performs any duplication of information that is required. The reproducer, as it is called, can perform many operations. Two of the most common operations are gang punching and straight reproducing.

(1) Gang punching is the automatic copying of punched data from a master card into one or more detail cards.

(2) Straight reproducing is the punched copying of data in whole or in part from one set of cards into another set of cards. Verifying and reproducing are done in the same operation.

b. Mark sense punching is usually an optional feature of a reproducer. By means of this feature, marks made by a special pencil on the card are automatically converted to punched holes in the card. The mark sense card has a capacity of 27 columns. The pencil marks themselves are not conductive enough to cause direct operation by the punch magnets; an amplifying unit is necessary. The control panel of the reproducer must be wired for this operation.

42. THE ACCOUNTING MACHINE

This is the basic device in the punched card system. The results of the operations of the other mechanisms in the system, useful as they are, are expressed only as holes in cards. Known also as the tabulator, the accounting machine summarizes and prints. Upon the completion of the operations by other mechanisms, it takes the data shown as holes in the cards, converts them to plain language, and prints them upon a report or other document. The principal elements of the tabulator are a reading unit, a printing device, a series of accumulators, and a control panel or wiring unit. The reading unit performs the usual function of sensing the holes in the cards. The tabulator prints all or part of the data from all or part of the individual cards, and accumulates, summarizes, and prints all or part of the data from all or part of a group of cards.

43. GENERAL

The input and output sections of a computer system provide means of communication between the computer and the user. The input feeds data into the storage unit. The output gathers the results from storage after computations are completed. Input and output are discussed together since the equipment in these computer sections may be used as either input or output, or used in the dual role of both input and output.

44. PUNCHED CARD INPUT

Punched cards are a primary form of input for many data processing systems. However, this means is relatively slow as the characteristics of the card itself and of the reader limit processing speed. Thus, in many instances, it is expedient to convert punched cards to magnetic tape prior to machine processing. In certain cases, the original medium must be converted to make the direct input medium compatible with the system design. For example, cards are converted to magnetic tape for use in a system that accepts only magnetic tape as input. Most manufacturers offer auxiliary component equipment to perform these conversions without tying up the central processing unit. Conversion to tape takes as much time as reading cards into the machine, but time is saved by performing the conversion while the central processing unit is operating on another job. Card readers available today accept cards at a rate of up to 2,000 cards per minute.

45. PUNCHED HOLE READING DEVICES

In general, there are two types of devices for reading the language on punched cards and punched paper tape. These two types are the mechanical and the optical reader. There are enough similarities between the devices that read paper tape and those that read punched cards as to consider them together.

a. Mechanical Readers. These readers sense the punched holes by using pins, pronged wheels, brushes, wires, pressurized air, and other methods to close an electrical circuit through the holes.

b. Optical Readers. Optical, or photoelectric, readers sense the punched hole by activating a light-sensitive photoelectric device. Light passes through the hole but is reflected off nonhole areas. Speed is limited only by photocell response or the operation of the card and tape handling mechanisms. Photocell readers can be used for high-speed applications (up to 2,000 characters per second).

46. MAGNETIC TAPE DEVICES

Each system capable of using magnetic tape as input or output has tape units to handle the reading of the magnetic tape.

a. Method of Reading and Writing. The typical tape unit has two tape reels; one contains the magnetic tape and the other is the takeup reel for the tape that has been read. The tape is transported from one reel to the other by a series of tape guides. Also contained in the tape unit is a read-write head, an erase head, and a photoelectric cell. The read-write head reads tape by translating magnetic spots to electrical impulses that are sent to the computer. It writes on tape by translating electrical impulses from the computer to magnetic spots on the tape. The photoelectric cell recognizes the end of the tape which is designated by a tape mark.

b. Interblock Gap. On magnetic tape it is necessary to have space between blocks. This space is required because of the speed at which the tape is read and written and also because there is no mechanical sprocket to facilitate tape acceleration and deceleration. When the machine writes a record, the tape accelerates to a very high speed. Similarly, it takes a fraction of a second to bring the tape to a standstill after the information has been written. Consequently, some amount of blank space (about three-fourths of an inch) exists between blocks of information. This space is known as interblock gap.

c. Advantage of Tape. Magnetic tape is the fastest of all input media, and it requires a relatively small storage space for a large number of records. The initial cost is the chief disadvantage of magnetic tape. It is the most expensive input or output media. However, because of the density with which the characters may be stored on magnetic tape, it is actually the least expensive medium per character representation.

d. Direct Preparation of Magnetic Tape. A manually operated keyboard device is used with some computers for preparing magnetic tape directly from source data. One such device records data on tape and produces a typed copy for verification purposes. This device holds a reel of blank tape and has a typewriter carriage. It also has a 120-digit core memory. As the operator strikes the keys and the characters are typed on paper, the core memory fills up. When 120 digits have been typed, the operator stops and checks the line of printed copy for errors. If none is found, the trip key is depressed. This action causes the contents of the core memory to be written on tape, spacing the tape forward to the beginning of the next block, and returning the carriage. If a mistake is discovered while typing a line, a backspace key erases from the core memory, a digit at a time, back to the correct digit.

47. PUNCHED CARD AND PAPER TAPE OUTPUT DEVICES

Card and paper tape punches are mechanical output devices that convert the electrical impulses from the computer to punched card and paper tape code. The impulses transmitted from the computer activate the dies that punch holes in the card or the tape. However, the mechanical features of punches make them a slow form of output.

48. PUNCHED PAPER TAPE

a. Paper tape is becoming an increasingly important medium for data storage in many applications. Once used only for message communication in five-channel teletype systems, paper tape is now being applied to many problems which had been previously handled by punched cards and magnetic tape. Standard paper tape is one inch in width and is compatible with some types of teletypewriter equipment.

b. Punched paper tape has columns similar to those on a punched card, but the number of columns is limited only by the length of the tape. In effect, paper tape is a series of miniature cards strung together to make up a roll. Punched paper tape can be classified according to the type of perforations made in the tape (chad, which has holes punched in the tape, and chadless, in which the perforations are not completely severed). The basic classification of paper tape, however, is according to the number of channels on the tape.

c. Teletype machines use the Baudot or five-channel code. Each character is represented by a five-bit code. A bit in any channel is represented by a hole in that channel, whereas a no-bit is represented by the absence of a hole. In this five-channel code only 32 different characters may be represented.

d. In actual operations, however, we need 36 letters and numbers plus several special characters. It is therefore necessary to make certain punch combinations do double duty as letters and figures by preceding them with a special shift punch to indicate whether we are representing letters or numbers. The two disadvantages of this coding system are that it holds a limited number of combinations and that it has no provision for checking accuracy.

e. There is a six-channel code that includes the provision for uppercase and lowercase letters. However, this system is rarely used in computer input since there is no need for this type of differentiation.

f. The seven-channel code is currently the one used most frequently. The code structure consists of a six-channel code with a seventh channel as a check channel. This number of channels enables each character to be represented by an odd number of holes. If a character is represented by an odd number in the six-channel code, no hole is added in the seventh channel, since there is already an odd number of holes. If a character is represented by an even number of holes in the six-channel code, a hole is added in the seventh or check channel.

g. Figure 20 shows a diagram of a portion of seven-level punched paper tape. This diagram illustrates the following terms used in discussing punched paper tape: frame, channel, and feed holes. Channels, levels, or tracks as they are sometimes called, are positions across the width of the tape in which data holes can be punched. A frame or row is a column of channels across the tape whose position along the length of the tape is defined by the feed hole.

h. As the tape moves under the reading head of the tape reader, punched tape is read one frame at a time. Each channel contributes its bit of input data, and the feed holes are used, among other things, to effect simultaneous transmission of the contents of the frames to the input-output register. The tape can be punched in teletypewriter code, bioctal code (two octal digits per frame), binary coded decimal, or any arbitrary code. In general, tape channels 1, 2, 3, 4, 5, and 6 store actual input data; the tape channel 7 stores the parity bit, and, in some cases, a special loading code. Since every character must be represented by an odd number of holes, any even-numbered combinations detected are interpreted as errors and cause an error indication to be made to the operator.

i. An eight-channel code system offers greater capacity. Because of this, it is gradually being accepted as standard.

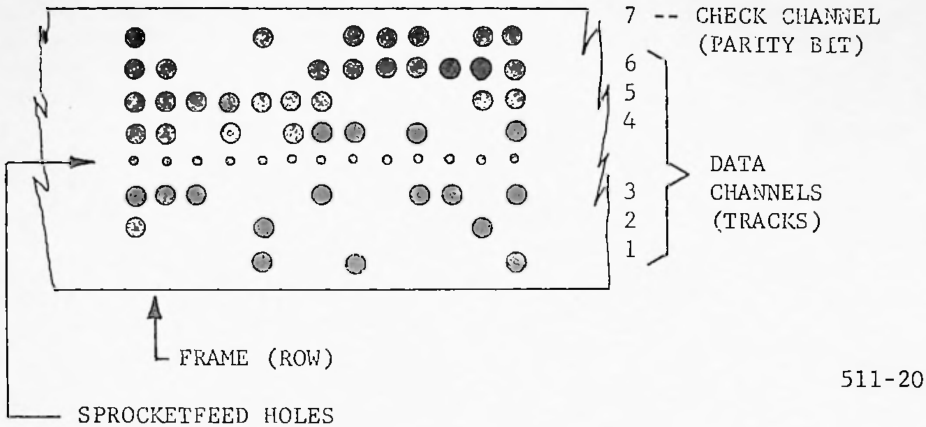


Figure 20. Seven-channel paper tape.

49. OTHER INPUT DEVICES

The following input and output devices are used when a small volume of input or output is desired. They are not designed for main volume input or output.

a. Console. On some systems, we can enter data or instructions into the computer by manually setting dials or buttons on the computer's console itself. The console is used to start a computer through a program, to correct minor errors, or to enter minor instructions or alterations in programs. By a method of controlling the step-by-step progress of the computer, we can read the contents of certain components of the computer by means of the lights on the console. In this way we can monitor our program progress and results. However, we must remember that the console is not designed for main volume input or output.

b. Console Typewriter. Most computers are equipped with a modified typewriter on the console. This typewriter may be used to put data or instructions into the computer. Usually, the typewriter is not used for volume input because it is limited to the speed of the typist. Instead, it is used to introduce small amounts of data or corrections of data already in the computer. Insofar as output is concerned, the console typewriter is used only for exception-type information, such as printing out the contents of a register at the end of a certain program or for testing programs. In doing this, the computer is stopped at a particular program step and the console typewriter prints that program step.

c. Inquiry System. Many computers have an inquiry system consisting of inquiry stations wired to the computer. These inquiry stations are standard typewriters, and may be located at varying distances from the computer. Inquiry stations allow the computer to be questioned about specific items of data, and provide the means for receiving answers. However, the program in the computer must be written to allow the inquiry either before or at the end of a series of computations.

50. OUTPUT

a. Once the computer has taken the input of data, been instructed what to do, and used its arithmetic and memory, it has done the bulk of the work of the problem. But it must now reverse the procedure. It could convey the answer to another machine that spoke its language, but this would be unintelligible to man. So the computer has an output section that translates back into intelligible language. Many of today's computers furnish punched cards or magnetic tape as output. Others print the answers on sheets of paper. Output may be in either semifinished or finished, nonreadable or readable form.

b. Semifinished or nonreadable output may take many forms, but the most frequently utilized types are magnetic tape and punched cards. There are several reasons for preparing output data in semifinished form.

(1) First, output may be written on magnetic tape and held for off-line, hard-copy reproduction when the speed of the available on-line printer limits the production or output of the system. Off-line tape-to-printer conversion takes advantage of the relatively high speed at which tape can be "written" as compared to the speed of direct, on-line printing. This operation, in effect, eliminates tieups and blocks that restrict the high computing and processing speed of the central processing unit. Much valuable processing time is lost when the central processing unit must wait for the printer to catch up.

(2) Second, preparation of output material in semifinished form facilitates further processing. For example, today's newly created and updated inventory file can serve as tomorrow's input, or a payroll record for this week can serve as next week's source input. It should be noted here that most systems allow for simultaneous production of both a finished and a semifinished copy. Thus, a daily stock status report may be prepared in finished form, while an updated tape file is created in the semifinished form.

(3) A third reason for creating an intermediate output is to facilitate further processing on a similar system at a remote location.

51. PRINTERS

Printing is another output medium. Printers can be classed either as electromechanical or electron-optical.

a. Electromechanical Printers. There are four types: the stick printer, the line-at-a-time printer, the on-the-fly printer, and the matrix printer.

(1) Stick printer. The stick printer uses an octagonal shaped printing stick to print the alphabet, the numbers 0 through 9, and 11 special characters. As the stick moves across the page of paper it revolves and positions itself to the proper letter, printing a character at a time. After printing each character, the stick moves one-tenth of an inch to the right. In operation, a platen the size of one character pushes the paper against the stick when the proper character is positioned. This process is continued until a maximum of 80 characters on a line is printed. The stick printer is the slowest device that can be properly classified as a printer.

(2) Line-at-a-time. There are two main variations of this kind of printer. One is the type bar, in which a gang of type heads rise and print the line at one time at a top speed of approximately 90 lines a minute. The other, the type wheel, gives greater speed (up to 150 lines a minute) since the character can be positioned more quickly on a wheel.

(3) On-the-fly. Rather than having an intermittent motion as do the machines mentioned thus far, the print wheel on this type of printer rotates continuously and a lightweight, fast-action hammer presses the paper against the wheel at the exact moment the required character is in position. This action gives these printers much higher speeds (1,000 lines of alphabetical characters per minute or 2,000 lines of numerical characters per minute). There are two principal kinds of on-the-fly printers: the solid drum and the multiwheel. The solid drum type has a complete set of characters for each printing position, with the horizontal lines across the drum consisting of the same character at each printing position. The drum printer prints all the characters that are identical at once in each line of print. The multiwheel type has one print wheel for each character position, and prints a line of 120 characters at a time.

(4) Matrix. A matrix printer is different from other mechanical printers in that no type slug or face is used. A matrix of wires is used at each printing position to form a character. A common matrix has many wires arranged in a very small rectangle. To print an "E", for example, the wires that form this letter are pushed out slightly by means of a push rod or hammer and strike the ribbon against the page, thereby printing the letter. Although a solid print does not result, it is legible enough for most practical purposes. This type of printer reaches speeds of 1,000 lines of 120 characters a minute. There are two kinds of matrix printers, one called the simultaneous printer and the other the scanning printer. The simultaneous printer pushes all wires necessary to form one letter at once. The scanning matrix printer uses rows of wires to print a line of characters.

b. Electron-Optical Printer. Electron-optical printers do not strike the paper as do the mechanical printers. The following types have been developed or are under development.

(1) Tube printers. One of these new types is the Charactron tube, a device combining a cathode-ray tube, something like a TV picture tube, with an interposed 64-character matrix about one-half inch in diameter. Electrical impulses deflect the beam in the tube so that it passes through the proper matrix character and forms an image on the face of the tube. This image is then printed electrostatically on a treated paper rather than with a metal type face. With no moving parts except the paper, and of course the electrons themselves, the Charactron printer operates close to the speed of the computer itself, and produces 100,000 words a minute.

(2) Display viewers. Another new development is a device that graphically displays data on the face of a cathode-ray tube.

(3) Haloid process. This process uses the electrostatic principle. Characters are formed with a wire matrix by scanning. Wires forming

the characters set up charged areas on the surface of a specially treated paper. A special powdered ink is used that clings only to the charged areas. The paper is then subjected to heat treatment to fix the ink.

(4) Ferromagnetographic. Magnetic principles are used in a device in which an invisible magnetic image of the data is recorded on a magnetizable surface. An ink containing particles of iron is sprayed on the surface and adheres to the magnetized areas. Printing on paper is done by rolling the surface against the paper.

52. SYNCHRONIZATION AND BUFFER STORAGE

Temporary storage of data is required to balance the various circuits in the computer components. Because the input, central processing, and output devices all process at different speeds, it is necessary to balance the components to eliminate delays in job processing and keep all areas operating as much of the time as possible.

a. Employment of off-line auxiliary operations is one method of economical use of computer capacity. Before processing, cards and paper tape are converted to the faster input medium of magnetic tape, and the computer creates a magnetic tape as direct output to be used in performing an off-line printing operation. This reduces the possibility of a tieup in the central processing unit.

b. Another way to coordinate the operations of the system is to increase the operating speeds of the slower components. For example, we can increase the speeds of the input and output devices to provide more synchronized production and effective use of the system.

c. A highly effective method of coordinating the components of the computer system involves the use of buffer storage units. The computer can accept and record data in storage faster than the input units can read it and faster than the output units can write it. To compensate for these differences in operating speeds, the buffer was developed. A buffer may be a small intermediate storage unit connected between the input unit and the internal computer storage or between the internal computer storage and the output unit. In other cases, a portion of the main storage unit is reserved for buffering.

(1) Input. The computer directs the input unit to read data into buffer storage. The computer continues with other operations until the read-in operation is completed. The computer then transfers data from buffer storage into the main internal storage at high speed. The effective input speed of buffer devices is much faster than the speed of input devices.

(2) Output. The reverse of this operation occurs when data is transferred from the computer to output units. The computer writes out data at a high speed into the buffer unit. The data is then transferred from the buffer unit to the output unit at the slower operating speed of the output device.

53. GENERAL

The capability of the computer to "remember" information is one of its most fundamental and essential characteristics. Actually, the computer remembers nothing. It must be told where to go to get data it has stored and what to do with it. All computers have areas, either within or outside the computer for the purpose of storing information. Each area is further divided into small separate areas of convenient size and assigned an address. Memory is the place within the computer that is capable of storing data for ready reference while it is processing a problem. Data is ultimately placed into storage in binary language. This language is used because the bits of this language can represent one of two conditions, plus or minus, positive or negative, or simply on or off. We know that the storage unit does not possess the creative properties of the human mind. Therefore, each digit or a series of digits must be specifically stored in an addressable location. Each instruction that requires the use of this data must refer to its exact location. The address of any storage location is one-of-a-kind, just like your exclusive telephone number. Thus, stored information can be accurately retrieved from storage when desired. Devices that are used for storage can be classified as being internal, external, secondary storage, or buffer storage facilities.

a. Internal storage elements are internal to a computer, and are considered to be the computer's primary storage units. Magnetic cores, drums, and disks are widely used as internal storage. Internal storage is characterized by medium-to-large capacity and low access time relative to the operating cycle of the computer.

b. External storage units are exterior to the central processing unit of the computer. This type of storage is not controlled directly by the computer, nor is it directly connected to the computer. External storage media include punched paper tape, punched cards, and magnetic tape. Access time is long because the media must be selected and manually inserted into an appropriate reading device. Punched paper tape and magnetic tape are in machine language. Punched cards, in most cases, must be converted to machine lauguage before the data can be processed. External storage is characterized by large capacity and long access time.

c. Secondary storage is external to the computer, but is controlled by and is connected to the computer. Magnetic tape is usually used, while magnetic disks are used in the newer equipment. These devices may be used along with internal storage. Secondary storage is addressable, but data so stored must be transferred to internal storage before processing can take place. This type of storage is characterized by extremely large capacity and long access time.

d. Matching the high speed of the computer with the slower speeds of peripheral equipment is the function of the buffer storage. A large capacity for storage is usually not required.

54. STORAGE DEVICE CHARACTERISTICS

Storage devices have certain characteristics. These devices are characterized by type, access mode, mode of operation, access time, capacity, readout, erasability, and cost.

a. Type. The type of storage device establishes the fact that it is either static or dynamic. Static storage is that from which the stored data is continuously available and is fixed in space. Examples of static storage are the magnetic core, magnetic tape, and punched cards. Information held in dynamic storage is moving in time and is not continuously available. The magnetic drum and disk are examples of this class of storage.

b. Access Mode. Access mode is the way a computer refers to stored data. There are three principal types of access: random, sequential, and a combination of the two. Random access means that information to be obtained from storage is, in essence, chosen at random. Sequential access means that desired data is located by searching through all locations, beginning with the presently accessible location, until the desired location is found. The combinational type of access is typical to, for instance, a magnetic drum. A drum has a number of tracks in parallel, each of which contains serially stored data. Access to a particular item of data on a drum means that a track must be specified (random access), and that the item desired must be searched for in that track (sequential access).

c. Mode of Operation. Mode of operation has to do with the way information is written into or read out of a storage location. There are three modes of operation: serial, parallel, and a combination of the two. In the serial mode, the data word is handled by bits, characters, and finally by the word itself, one after another in sequence. In the parallel mode, all the bits and characters of the entire word are read simultaneously. In the combinational mode, a word can be treated serially by digit, and parallel by bits which make up the digit.

d. Access Time. Access time of a storage device is the delay or interval of time between the calling for data from storage and the receipt of the specified information.

e. Capacity. Capacity of a storage unit is the amount of data it can store at one time. Data consists of bits, characters, or words. Capacity may be further expressed as being of either fixed or variable word lengths.

f. Readout. Readout can be either destructive (volatile) or nondestructive (nonvolatile). When data is read out of storage, and the data is retained in storage, then the data is said to be nondestructive. On the other hand, if data is lost on readout, it is considered to be destructive. Further, data that could be lost as a result of a power failure, is considered to be volatile.

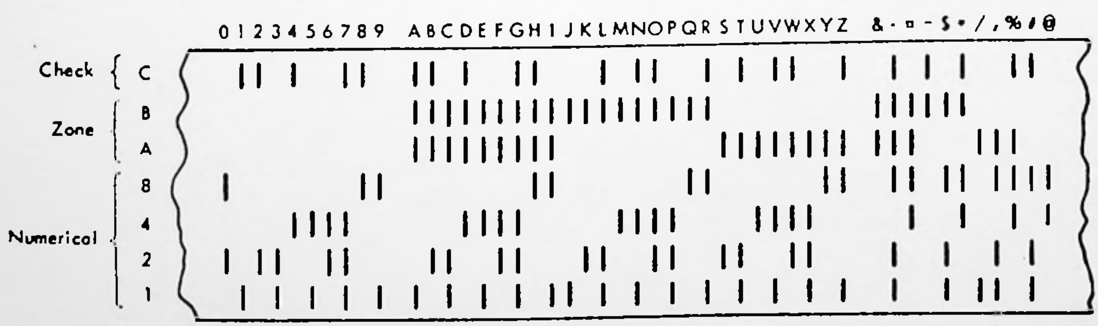
g. Erasability. Erasable data is that data written in storage that can be replaced by other data when necessary. Magnetic tape has this capability; punched cards and punched paper tape do not.

h. Cost. Storage devices are characterized by cost per bit. Punched cards and magnetic tape are the least expensive of storage media, running to about $0.000002 per bit. Magnetic core storage, while not the most expensive, averages $2.25 per bit. The vacuum tube was the costliest, averaging $10.00 per bit.

55. TYPES OF STORAGE DEVICES

There are many types of storage devices that are used in computer memory units. Among these are the magnetic drum, magnetic core, magnetic disk, electrostatic storage device, acoustic delay line, thin film, and magnetic tape. These have been touched upon earlier. However, it is well worth the effort to further explore the more popular types and those that show promise of becoming memory units.

a. Magnetic Tape. Magnetic tape is made from finely ground iron oxide particles distributed in a coating on acetate, aluminum, or other nonmagnetic metal or substance. Physically, the tape is usually 1/2 inch in width, with 2400 feet wound on a 10-1/2-inch reel. Magnetic tape can be classified according to the type of material and according to the number of channels. For instance, numeric computers use a five-channel code while alphanumeric computers use a seven-channel code. An eight-channel code is sometimes used, with the eighth channel being used for timing purposes. A channel check is always used in magnetic tape coding. The code for each character consists of a combination of magnetic and nonmagnetic spots. Tape is usually recorded serially by record, word, and character, and parallel by bit. Data is recorded in blocks of convenient size, with an interblock gap between blocks. Blocks are further subdivided into records, with so many words or characters each. Either some space or no space at all is provided between each record. Reference to figure 21 and to figure 14 will give you a good idea of one type of coding that is used. Digital recording is sensitive to tape dropout errors; lost or spurious bits result in computation errors. For this reason, special precautions are taken in the manufacture, inspection, and selection of tape intended for digital recording. Safeguards are built into the digital recording process to provide greater reliability against tape dropouts or other errors. One of these is the use of the redundancy technique, in which the same information is recorded twice. A second scheme is the use of a parity check (the channel check), in which one track on the tape is reserved for a pulse which is derived from the pulses being recorded simultaneously on the other tracks. A parity pulse is of such polarity that the sum of all bits on playback (including the parity bit) will be either an odd number or an even number, depending upon the system used.



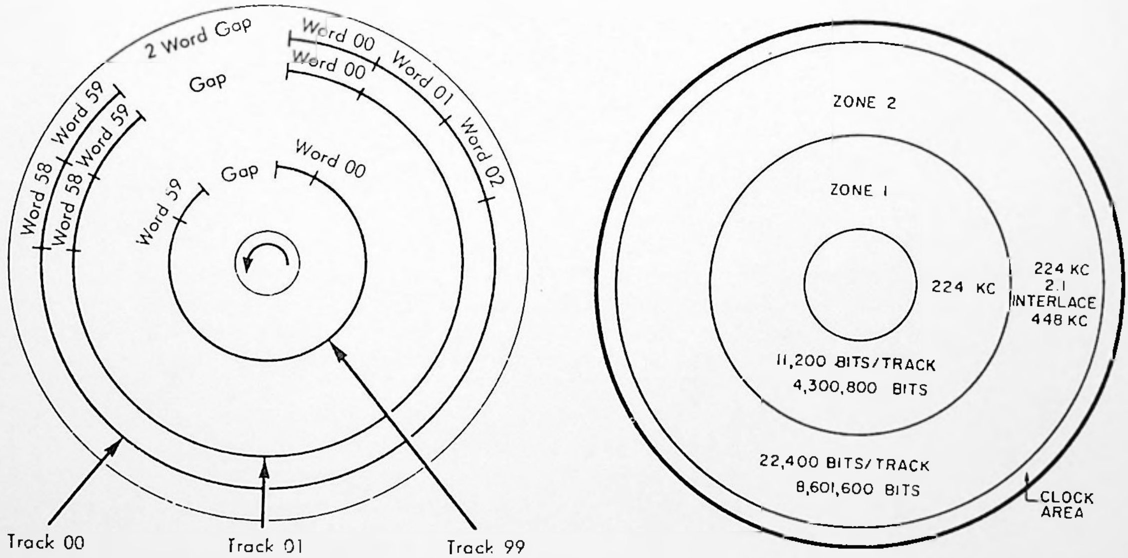
511-21

Figure 21. Seven-channel coding.

b. Magnetic Disk. A magnetic disk file may consist of a single flexible disk, or a number of rigid disks, mounted horizontally or vertically on a shaft. The diameter sizes of disks vary from 7.75 inches for the LFE (Laboratory for Electronics) BD-10 series disk file to 39 inches for the BRYANT 4000 series disk file. Disks are rated as to capacity (in bits), number of tracks, average access time, speed of disk rotation, and the technique used in recording and reading information.

(1) Capacity. Capacity varies greatly between disk files of the various manufacturers. This ranges from 25,000 bits to 720,000,000 bits per unit. Capacity, of course, is dependent upon the number and size of disks used, and the technique used in packing bits on the recording surface.

(2) Tracks. Each disk consists of a number of concentric tracks, usually on both surfaces, on which data is written. Records are written serially within a track, then serial by word, serial by character, and serial by bit. Disk files definitely have random accessibility. Various methods are used in the arrangement of tracks. The number of tracks per disk range from 12 of one manufacturer to 736 of another. Figure 22 shows two different track arrangements. Disk storage is permanent. Data will remain stored indefinitely, and can be read out as many times as desired. Stored data can be replaced by writing new data in its place.



511-22

Figure 22. Magnetic disks.

(3) Access time. Access time varies, for example, according to the type of disk unit, whether read/write heads are fixed or movable, and the number of heads employed. In some units with movable heads, time is required to locate the desired track and disk. This is called seek time. Then time is required before the information is

delivered for processing. This is access time. In practice these two times are lumped together and are designated as the access time. On the other hand, disks that use fixed heads already have the heads positioned over the tracks and thus need no seek time. Access time for different disk units ranges from as little as 8 to over 1,000 milliseconds.

(4) Disk speed. Disk rotation speed ranges from 900-12,000 revolutions per minute, depending upon the type of unit.

c. Magnetic Drum. The physical dimensions, rotation speed, number and type of heads, and the arrangement of data have an effect on the access speed and capacity of a drum.

(1) Magnetic drums of various manufacturers differ in size and in data-storing capacity. One of the smallest drums has a diameter and length of 1-3/4 inches by 2-1/3 inches, respectively, and a capacity of storing 11,500 bits on 18 channels or bands around the drum. Another type of drum is 18-1/2 inches by 34 inches, and has a capacity of 30 million bits on 1,800 channels. Compared to this, a larger drum of still another manufacturer (31 inches by 48-1/2 inches) has the capacity to store slightly more than 28 million bits on 768 channels. Read/write units are located in a line parallel to the surface of the latter make of drum, usually one per channel. These record/read heads on most machines do not actually come in contact with the surface of the drum. Some ride on a cushion of air, some drum systems use filtered oil to provide the necessary clearance, while others have a fixed tolerance between head and drum.

(2) As the drum rotates, each of the words of a record passes in series and the character bits pass in parallel. Drums are classed as fixed word length devices. The drum is addressable by word location. Access time is equivalent to the time required for the drum to make one-half of a revolution.

d. Magnetic Core. The ferromagnetic core has already been mentioned. Another type of core is made of a doughnut-shaped plastic spool with a thin strip of magnetizable metal wound on the spool. Both types, however, work similarly.

(1) The magnetic core possesses certain properties in the way it can be magnetized. Because of the way it is wired, the core is not influenced by any stray magnetic fields. The core can store binary information because it has the capability of being in one of two stable states at any one time, i.e., either positive (the "0" state) or negative (the "1" state). The energy stored in a core can be used to develop an output pulse when the core flux changes polarity. The way a core is wired is shown in figure 23.

(2) The four wires threaded through the core are used to control the status of the core to either store or readout information. To store information, the X and Y wires are used. To readout information, all wires are used as explained in (4).

Magnetic Core
(Actual Size)

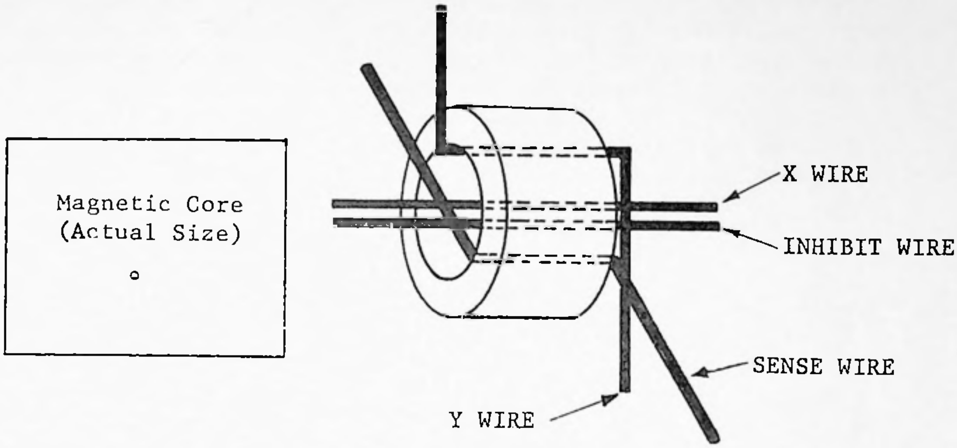


Figure 23. Core wiring.

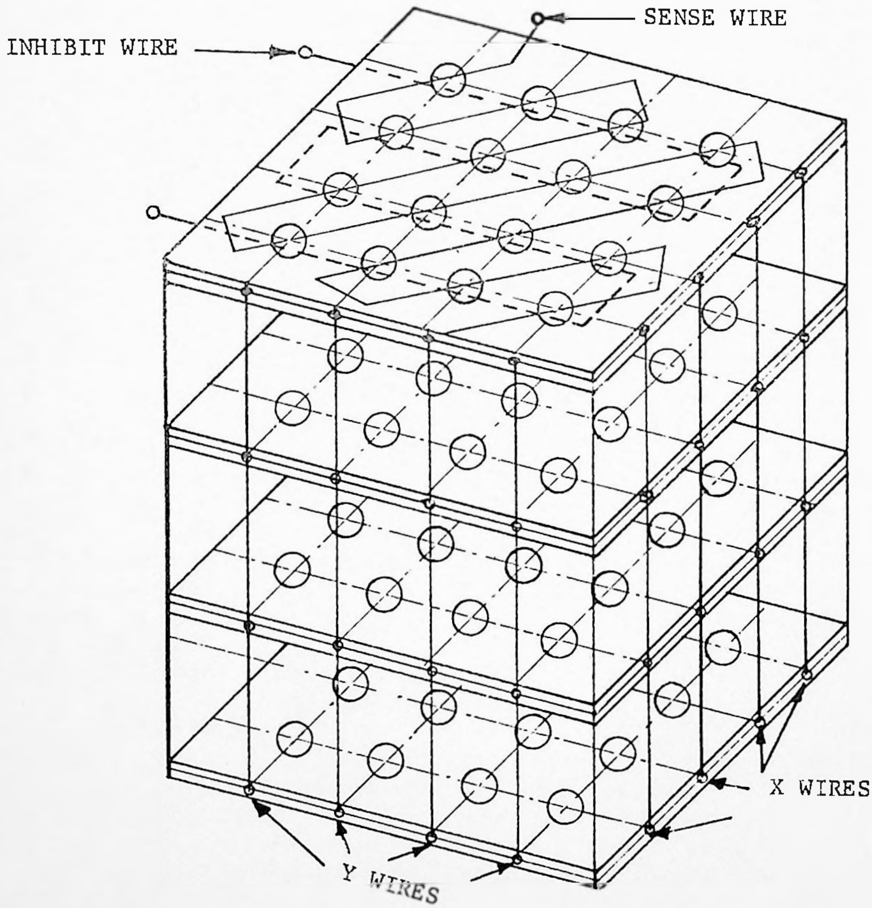
(3) Information is entered into the core by means of the X and Y wires. One-half of the current necessary to change the state of the core is placed on each wire. Where the wires intersect, the sum of these two currents cause the core to change its state. Current sent in the opposite direction will cause a change in polarity of the core.

(4) Information is read out of the core by sending current through the same X and Y wires. If the core changes its state, the changing magnetic field creates a current in the SENSE wire, and we know that a "1" was stored there. If no current is created in the SENSE wire, a "0" was stored in the core. The reading out process causes the negative polarity bits stored (the "1's") to be destroyed as the core returns to its normal "0" state. The "0's" that are read out simply lose what little charge they had. Information that must be retained must be rewritten into the core.

(5) Information is rewritten by the INHIBIT wire. All cores in a particular address are set to "0" when reading out. On the rewrite cycle, the cores that were previously in the "0" state must be left unchanged, and a "1" rewritten into the cores that were previously in that state. Current is sent through the appropriate X and Y wires, thus setting the cores back to their original "1" state. If an "0" is required to be retained in a particular address, current is sent over the INHIBIT wire along with the current through the X and Y wires, with the net result that there is no change in the "0" state cores.

(6) Why use the two wires, X and Y, when one would do the job if enough current were sent through it? The answer is that only one core is to be selected for reading or writing from a great many cores surrounding the selected one. In a complete core memory unit, each core is assigned a letter or number to correspond to the information to be stored. Several thousand cores may be used in an arrangement called a matrix. Each X, Y, SENSE, and INHIBIT wire is strung through all of the cores. To select one core in a matrix, one X

wire and one Y wire are selected and electrically pulsed. Only at the intersection of these wires will there be enough current to change the state of that particular core. Several matrices may be placed together in planes, one above the other (see fig 24) to form a core memory. By connecting corresponding X and Y wires in all matrices, several cores, one from each plane, may be read out simultaneously. Each plane must have its own SENSE and its own INHIBIT wire.



511-24

Figure 24. Core memory matrix.

e. Magnetic Thin Film Storage. Thin film storage is the latest production device in use. This memory is similar to core storage in that switching to either of the two stable states is based on the Hysteresis principle. Thin film memories require no threading of wires through holes and therefore can more easily be constructed by printed circuit techniques. The storage element consists of a thin film of nickel-iron alloy which has been deposited on a suitable base by a vacuum or electroplating process. One type of thin film element is composed of round spots 3/16th of an inch in diameter. Another type uses rectangular spots 3/16th by 1/8th of an inch in size. The films are deposited in the presence of a magnetic field, and as a consequence show a preferred direction of magnetization. The direction of magnetization can be represented by a magnetic dipole (like a compass needle) which has two stable states parallel to the preferred direction, the unit and zero states. (See fig 25a) An appropriately applied magnetic field can cause the film dipole to rotate out of its "1" or "0" state; when the field is removed, the dipole will rotate back to the nearest stable state (the state requiring the least angle of rotation). Three (printed) wires are required, the W wire characteristic of a word, a Y wire characteristic of a bit of the word, and an S wire that senses the read-out signal for a bit, oriented as shown in figure 25d with respect to the preferred direction of the film spot.

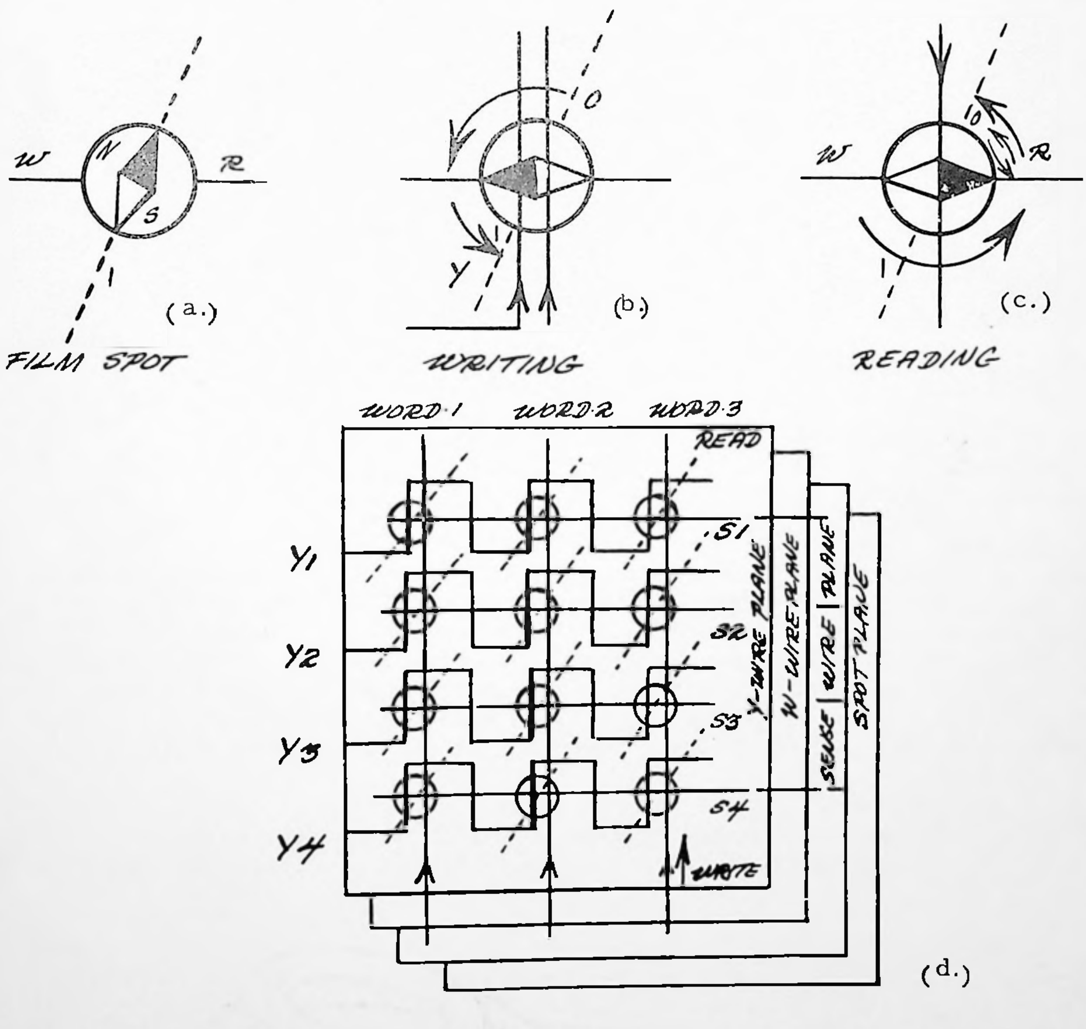


Figure 25. Thin film memory.

(1) The films of a storage location are always reset to "0" before a word is written into it. The directions of the W and Y wires are parallel at the film spot, making an angle of 30° with the spot's

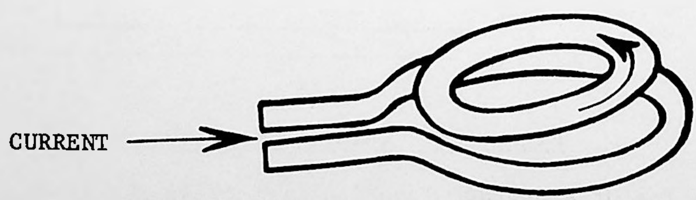
preferred direction. When it is desired to write into a memory location, a current is applied to the corresponding W wire. For the "1" bits of the word, a current in the same direction as that of the W wires is applied to the Y wire; for the "0" bits of the word, a current in the opposite direction is applied to the Y wire. For the "1" bits, the combined applied fields of both W and Y wires rotate the magnetization to the W direction (see fig 25b); when the applied field is removed, the magnetization rotates to the "1" preferred state since this is closest. For the "0" bits, the effects of the fields applied by the W and Y wires cancel, and the magnetization stays in the "0" state. The field applied to the nonselected word spots by the current in the Y wire is not in itself sufficient to rotate the magnetization over 90° from the preferred direction, and hence these spots are not affected.

(2) To read a word from memory, a current is applied to the W wire in the direction opposite to that for writing. The "0"-state spots rotate from the "0" direction to r (see fig 25c); the "1"-state spots rotate from the unit direction also to r, but the rotation occurs in the opposite sense to that of the "0"-state spots. The sense wire S, placed perpendicular to the W wire to minimize stray pickup, gets a negative induced current from the former rotation; these currents correspond, respectively, to sensed "0's" and "1's".

(3) However, both "1" and "0"-zero spots will return to the "0" state, and, as in the case of the memories described above, the word must be read back by means of the usual read-write cycle. Figure 25d shows a memory of three 4-bit words; the three wire planes are printed separately and placed over the spots as shown. Actually, for greater sensing signals, two spots per bit are used in a slightly different arrangement.

f. Cryogenics. Cryogenics is the study of extremely low temperature phenomena. Cryotron is the name given to a switching device whose operation is based on superconductivity, which occurs at extremely low temperatures. When certain elements are cooled to near absolute zero temperature, their electrical resistivity drops practically to zero. This transition into the superconductive state occurs at a sharply defined temperature, which is characteristic of the element but can be altered by an applied magnetic field. In general, the greater the magnetic field, the lower the transition temperature.

(1) Consider a closed loop of superconductive metal and in close proximity to it, another driving loop (fig 26). Let us suppose that a superconductive current flows in the closed loop in a given direction



511-26

Figure 26. Cryogenic storage loop.

as a result of the previous write-in. Let the current in the driving loop rise and the polarity be such that the induced current in the loop will tend to increase the supercurrent. The loop current will increase until it reaches a critical value, at which time the loop becomes normal and the current starts to decay as a result of the nonzero resistance. If the drive current is maintained, the loop current will decay to zero. This occurs due to Joule heating of the loop by its current, which raises the temperature sufficiently to decrease the critical current and keeps it lower than the current, so that the loop does not become superconductive until the current has decayed to zero. Now if the driving current is turned off, a supercurrent of opposite polarity will be induced which will not reach the critical value since there is no previously induced additive current. In this way the supercurrent of the loop is switched. The operation is similar to that of an element possessing hysteresis (delay in reacting). There are two distinct remaining states corresponding to the two directions of flow of the supercurrent. These states persist indefinitely without any external holding energy. To switch from one state to the other, the drive must exceed a certain threshold in the direction establishing the desired state. Reading out of information is similar to magnetic core. With use of thin film fabrication techniques to connect the elements, these devices have nondestructive read-out.

(2) Advantages of superconductive memories include switching times on the order of nanoseconds, sharp switching thresholds and stored energy per bit can be very low. Elements can be packed one hundred to the centimeter. Refrigeration at present is a problem since special experimental techniques are required. Liquid helium, although reasonable in price, is not always readily available. However, closed cycle refrigerators are being developed for this device.

g. Photographic Film Storage. Photographic film storage can store data at one thousand bits per inch of track and one hundred tracks per inch. Extremely high reading rates permit scanning the whole file so that serial access and sorting problems are less critical. This type of storage cannot be updated directly, but changes can be stored in subsequent records and both old and new records considered together. Occasionally these records can be merged. This is used for language translation and vocabulary use.

56. GENERAL

a. The central processing unit of a computer is referred to as the main frame, and consists of the control unit, arithmetic and logic unit, and an integral storage unit. It is here that the data is manipulated, arithmetical computations performed, and comparisons made. Information flows in a complex fashion between these elements--the internal storage unit receives input data and instructions during processing and furnishes results to the output unit; the arithmetic and logic unit calculates; and the control unit controls the operations of the whole system.

b. To fully appreciate the speed, efficiency, and accuracy of the computer, an understanding of the principles upon which it operates is necessary. For this reason, we will discuss in detail the three components of the central processing unit.

c. As you have already learned, all information being processed is stored in the storage unit of the computer (storage is the preferred term, although it is interchangeable with the term memory). The size of the computer storage may range from a capacity of two hundred to over twelve million decimal digits. Capacity is the total amount of information a storage unit can retain. Capacity is expressed in bits (binary digits), or as words when the number of bits per word is known. Information can be erased from storage by writing new information in its place.

57. MYTHAC CENTRAL PROCESSING UNIT

a. The workings of the control unit and the arithmetic and logic unit, their relation to each other, and to the storage unit, are best explained by a mythical computer--the "MYTHAC." MYTHAC is nothing more than a "paper" computer devised and used at the Signal School as a teaching aid in presenting instruction to resident students. The MYTHAC computer is realistic in its operation, and is general enough so that its operational concept can be applied to an actual computer. MYTHAC has a 2,000-word core memory. A computer word is a group of characters, digits, or binary symbols that occupies one storage location, and is treated by the computer circuits as one unit. A computer word in MYTHAC's case is six decimal digits long, plus an algebraic sign. Seven binary digits are required for each character. When a word location in storage is addressed, the entire contents of that memory location are retrieved. There are two types of words: the data word, and the instruction word. These two types of words are the computer input.

(1) A data word is an item of information that is contained in one storage location which is to be worked on. Examples of this are numerical constants, tables of figures, or statistics.

(2) An instruction word is written by the programer telling the computer what to do.

b. A data or instruction word may be stored in any of the storage locations. The normal procedure is to store both types in memory. The memory locations for MYTHAC are numbered from 0000 to 1999.

c. Let's look at figure 27, which diagramatically shows the three components of MYTHAC. The component on the left is the control unit. The center unit is the memory, and the right unit is the arithmetic and logic unit. Each line of storage represents one storage location, and for our purpose, only a few of the 2,000 locations are shown.

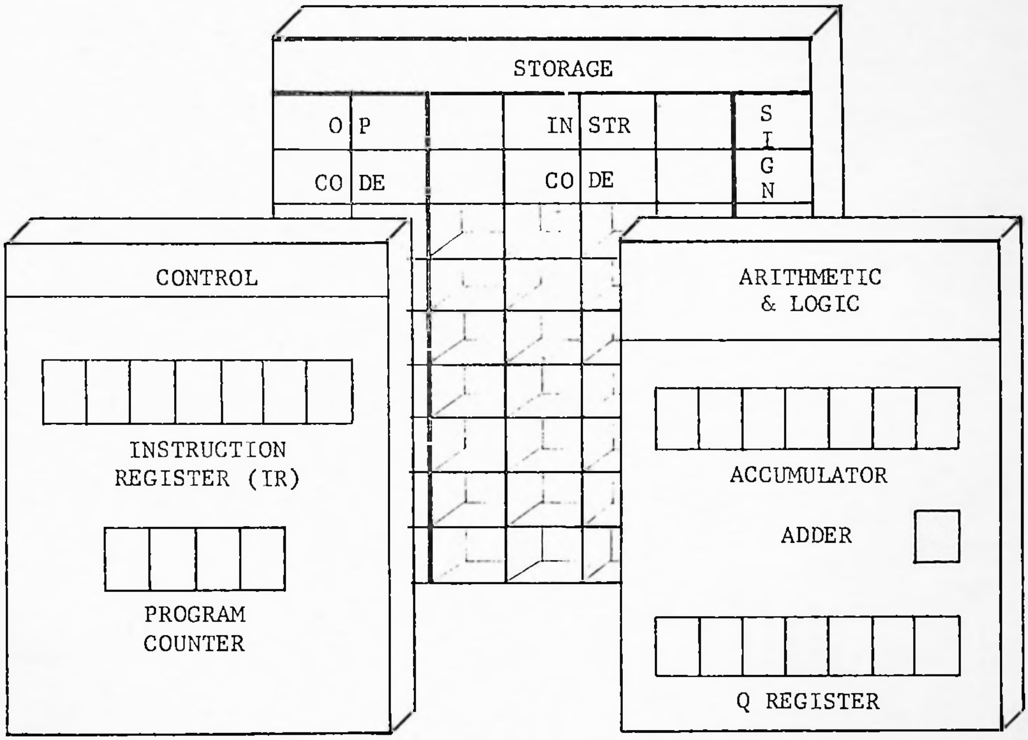


Figure 27. MYTHAC central processing unit.

d. As you can see in figure 27, the control unit consists of the instruction register (IR) and the program counter (PC). The instruction register is the temporary storage in which each instruction is held after it is brought from memory and while it is being analyzed. The program counter keeps a running record of the storage location of the next instruction. The main function of the control unit is to analyze the instruction register and to set up the necessary circuits for its execution. MYTHAC is a sequentially programed computer, that is, the instructions follow in sequence.

e. The arithmetic and logic unit is the heart of the system. The unit consists of two registers: the accumulator (ACC) and the Q register (Q). These registers temporarily store data to be worked on. The unit also has a 1-digit adder which takes care of the actual arithmetic processes. Addition or subtraction is accomplished by passing the two factors involved through the adder. These factors are fed to the adder, one digit at a time, starting with the digit in the right-hand position (low order digit) in the registers. The adder has three inputs: one from the Q register, one from the accumulator, and one from the carry. The carry input occurs when the sum of the digits is

10 or more. When two factors are to be added, the first factor from storage is placed in the accumulator. The second factor is placed in the Q register, and is added to the first. In case of a carry, the circuit is set to increase the sum of the next set of digits by one. The operation appears as figure 28 illustrates, with the results being stored in the accumulator.

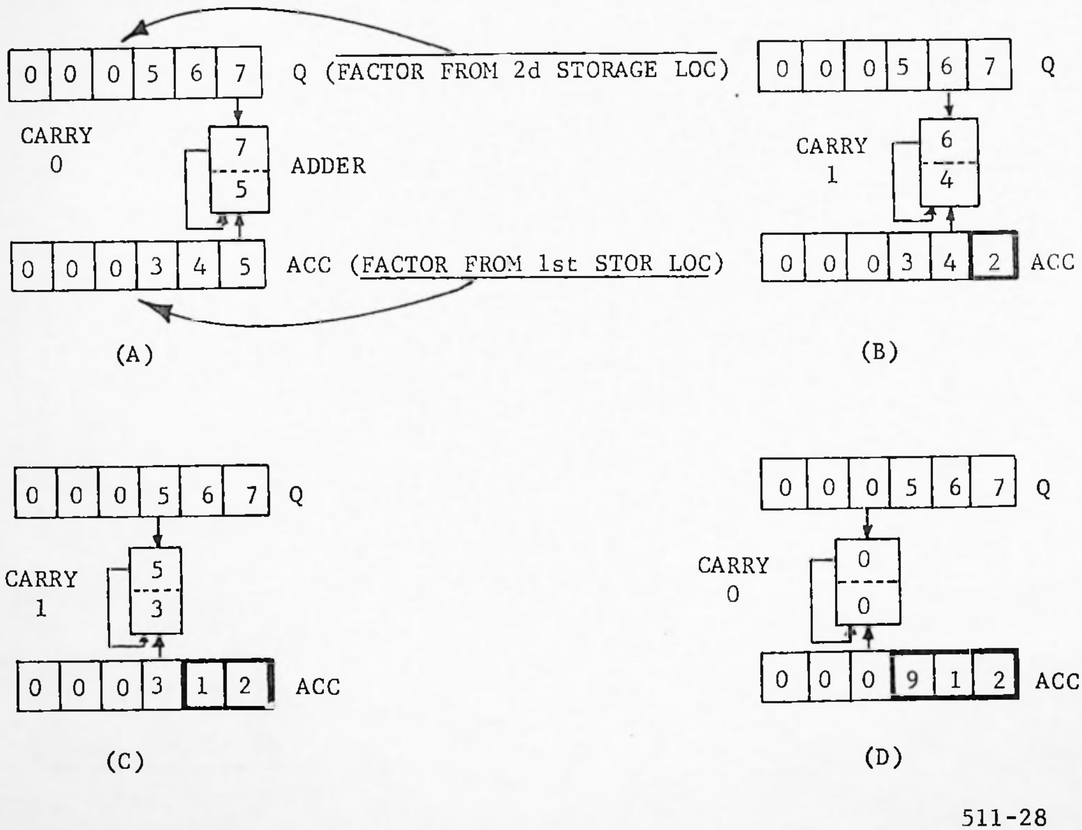


Figure 28. Operation of the 1-digit adder.

f. Let us examine the process how the 1-digit adder accomplished the arithmetical operation of addition.

(1) Figure 28 (A) shows the Q register input digit 7 and the accumulator input digit 5 passing through the adder.

(2) In the next step, shown in figure 28 (B), a one-position shift of the two factors takes place. Inputs 6 and 4 pass through the adder. The result from the previous step (7 + 5 = 12) is placed in the accumulator in the units position with a one to carry, replacing the digit already there.

(3) In figure 28 (C), another shift to the right occurs. Inputs 5 and 3 pass through the adder. The sum of the previous step (6 + 4 + 1 = 11) is placed in the tens position in the accumulator with a one to carry.

(4) Figure 28 (D) shows the inputs 0 + 0. The one carried over from the previous step is added to the sum of 5 + 3 and the result placed in the accumulator in the hundreds position. The accumulator and the Q register continue to shift to the right throughout the remaining positions, one at a time. The arithmetic operations affect all positions of the accumulator. The new factor 000912 has now replaced the previous factor in the accumulator.

g. Now, let us consider the MYTHAC instruction word and see how these instruction words are used to instruct the machine. A list of instructions, called a program, is prepared by the programer. Our instruction word is a single address word, and as we said, is six digits long with a sign. This means that the instruction word contains an operation code and one address. Figure 29 shows its form.

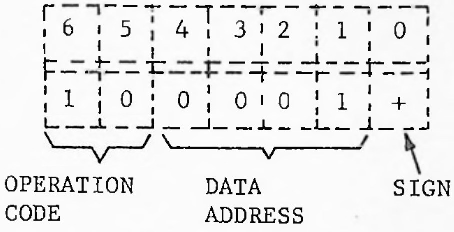


Figure 29. Instruction word form.

h. All instruction words are loaded into storage by means of a loading routine prior to the start of an operation. The operation code specifies the operation to be performed. The data address designates the address of the data involved. The sign is disregarded in the analysis and execution of the instruction.

i. To start the program, necessary switches and contact buttons on the MYTHAC console are set. The location of the first instruction is set by these controls on the console. The first instruction is transferred out of storage into temporary storage in the instruction register. This register is a copy of the instruction word with a place for the operation code and an address.

j. MYTHAC is now ready to go through a simple addition operation to illustrate how instruction words instruct the machine. The instruction word will tell it what to do by means of the operation code, and the data address will tell it where to go to get the data that is to be acted upon. The program counter provides the continuity by telling the machine where to go for its next instruction.

k. An instruction to our processor is executed in two steps called half-cycles. The first half-cycle of the execution is called the data half-cycle. The second half-cycle is known as the instruction half-cycle.

l. Let us assume that we want to add two values together. MYTHAC has just completed an instruction and the program counter shows 0013 as the location of the next instruction (see fig 30). We go to this location and we find the instruction to be 100304+. This tells the machine to add (operation code 10) the contents of the data location (0304) to something. The contents of 0304 happen to be 000567, and are read into the accumulator, which has been previously cleared to zero. The operation to this point is the data half-cycle. The program counter, being sequential, steps up to 0014 as the location of the next instruction. The instruction register is reset. This occurs during the instruction half-cycle. The next instruction is found in location 0014

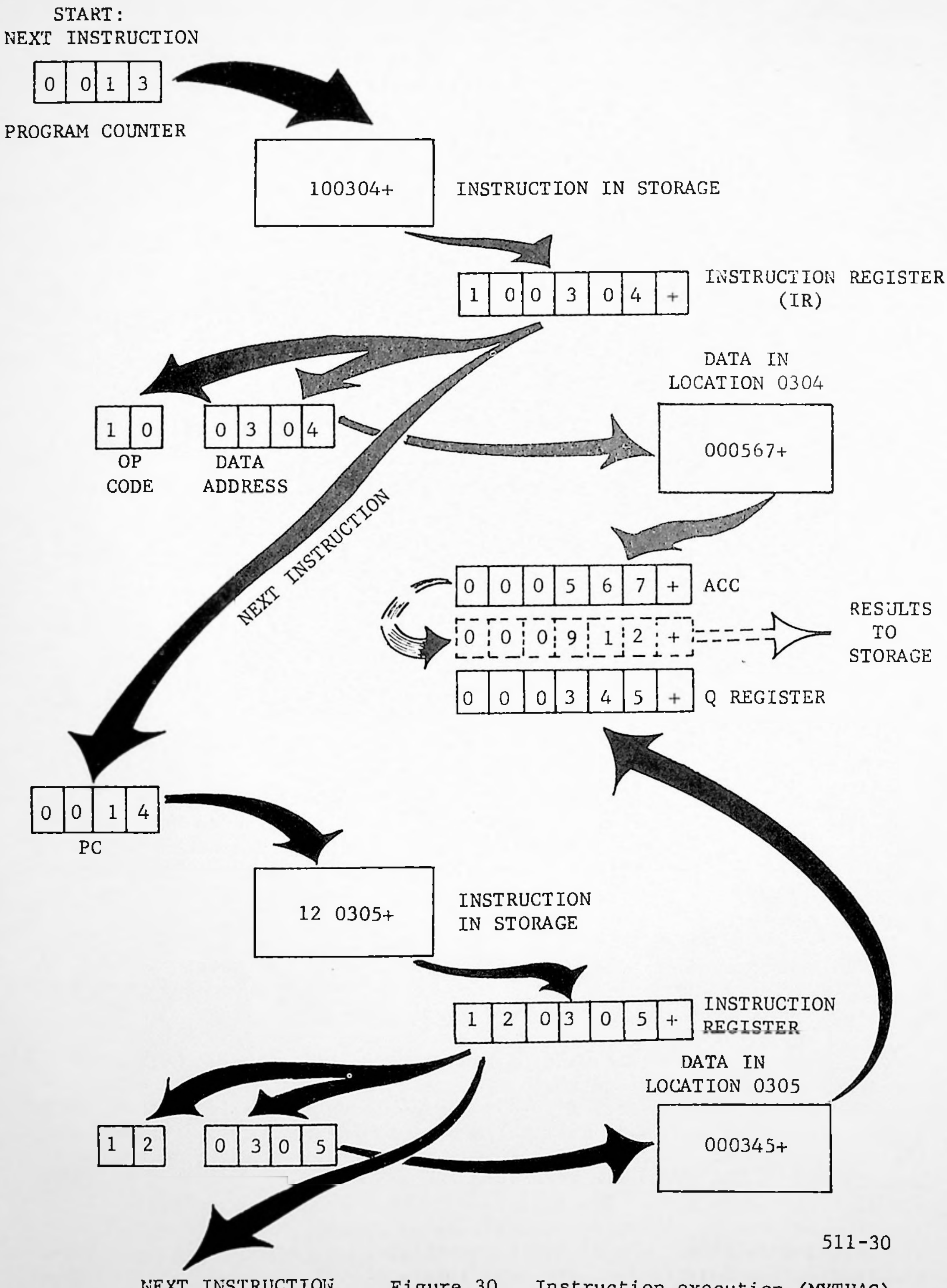


Figure 30. Instruction execution (MYTHAC).

and happens to be 120305+. This tells the machine to add the contents of data location 0305 to the contents of the Q register. The contents of 0305 is 000345 and are read into the Q register. The two factors are added together by the 1-digit process explained earlier. One more thing remains to be done, and that is, we must do something with the result of the addition. A "store" instruction to the machine will tell MYTHAC to store the contents of the accumulator (000912) in a specific data location, replacing whatever happened to be already there. It is in this manner that the machine steps through a program. It advances from instruction to instruction in sequence without stopping until the program is completed.

58. REVIEW OF MYTHAC OPERATIONS

Let's review the salient features of the arithmetic and logic unit we have covered so far.

a. The instruction word being executed is contained both in storage and in the instruction register.

b. The program counter is increased by one to show the location of the next instruction.

c. The accumulator and the Q register each have a capacity for six digits plus a sign. These registers are cleared to zero before an operation is started.

d. The machine can add only two numbers, and it accomplishes this by means of the 1-digit adder.

59. SUBTRACTION, MULTIPLICATION, AND DIVISION

Besides the add capability, MYTHAC has the capability to subtract, multiply, and divide. The addition process has been explained (par 57g-m).

a. The subtract operation works exactly like the addition except that the number to be subtracted is complemented. The subtraction is performed by the process of addition in the 1-digit adder. This process may be illustrated by the following example:

To subtract 248 from 682, we would go through the following steps:

Step 1. Complementing 248 gives us 752. This is the tens complement and is obtained by subtracting 248 from 1,000.

Step 2. Adding 682 to 752 gives us 1,434.

Step 3. Eliminating the left-most digit gives us the correct answer of 434.

b. Multiplication is done by a series of repeated additions. For example, if 10 x 10 were to be calculated, the computer would actually add 10 to itself 10 times.

c. Division is done by a series of repeated subtractions. These subtractions are in turn done by complementing one number and adding, as explained above for subtraction.

60. GENERAL

A computer has many different kinds of circuits to direct and do all its operations. The circuits we will consider in a general light are the ones that form the logic circuitry of a computer. It is the intent that you should, at least, become acquainted with the types of circuits that are basic to a computer. There are three types of circuits used, alone and in various combinations. These are the flip-flop (FF) circuit, the "AND" circuit, and the "OR" circuit.

61. THE FLIP-FLOP CIRCUIT

a. A flip-flop circuit consists of a bistable device capable of representing a binary bit of information. During operation, it is either on or off but never both at the same time. One of its states represents a "1" and the other state represents a "0." A flip-flop is represented by the circuit shown in figure 31.

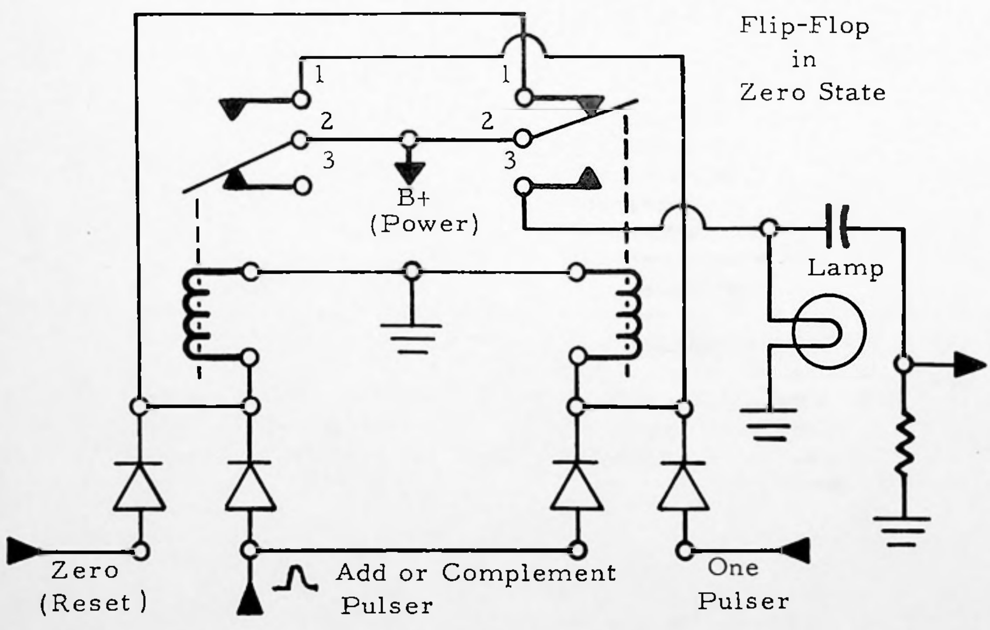


Figure 31. Flip-flop circuit.

b. The device is operated by electrical pulses passing through inputs to the device. Usually, there are three types of input pulses: the add or complement pulse, the reset (or zero) pulse, and the "1" pulse.

c. A pulse coming into the complement input will trigger the device, causing it to change from one state to another. This change is called complementing. Another pulse coming in on the same input will cause the circuit to change back to the zero state. It takes two pulses to "add or complement" for a complete flip-flop circuit.

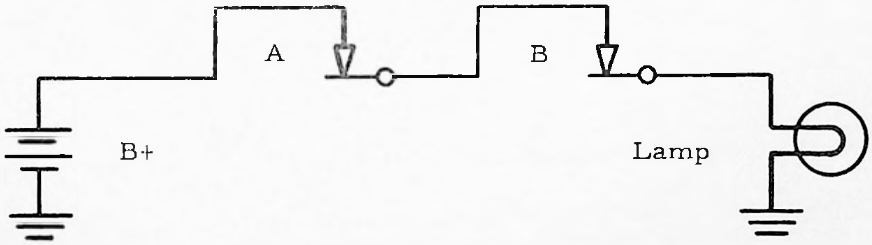
d. A pulse on either of the other inputs will cause the circuit to be set to that state. A pulse on the reset or zero input will cause the device to go to the zero state; a pulse on the "1" input will cause the device to go to the "1" state.

e. It takes more than a flip-flop circuit to make a computer perform all the tasks required of it. The basic flip-flop device will add binary digits, but will not perform the functions of multiplication, subtraction, and division without the other types of circuits mentioned.

62. THE "AND" CIRCUIT

a. The "AND" circuit is one of the two most used logical circuits (the other being the "OR" circuit). An elementary "AND" circuit can be thought of as a series circuit composed of switches, each of which must be closed in order to produce an output (see fig 32A). It can readily be seen from the diagram that there will be an output only when both switches (A "AND" B) are closed at the same time. The statement for the circuit may be written in several ways, the more common of which are shown in figure 32B.

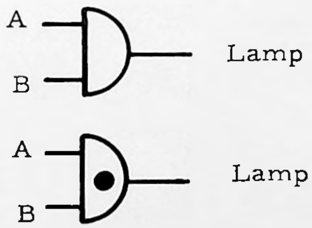
(A)



(B)

A "AND" B = Lamp,

or A · B = Lamp,



511-32

Figure 32. The "AND" circuit.

b. In practice, electronic devices such as transistors are used rather than some mechanical means for switching. An output is present only when all of the inputs are present, and the output is proportional to the smallest input.

63. THE "OR" CIRCUIT

a. A basic "OR" circuit can be thought of as a parallel circuit composed of switches, any of which may be closed to produce an output (see fig 33A).

It can be seen from the figure that if switch A "OR" B is closed (or both), the lamp will light. The statement for this circuit may be written in several ways, the more common being shown in figure 33B.

b. The sign (+) does not mean "AND" in this form of symbolic logic. It means "OR." As in the "AND" circuit, electronic switching devices are used. Output is present when any of the inputs are present, and the output is proportional to the highest input voltage.

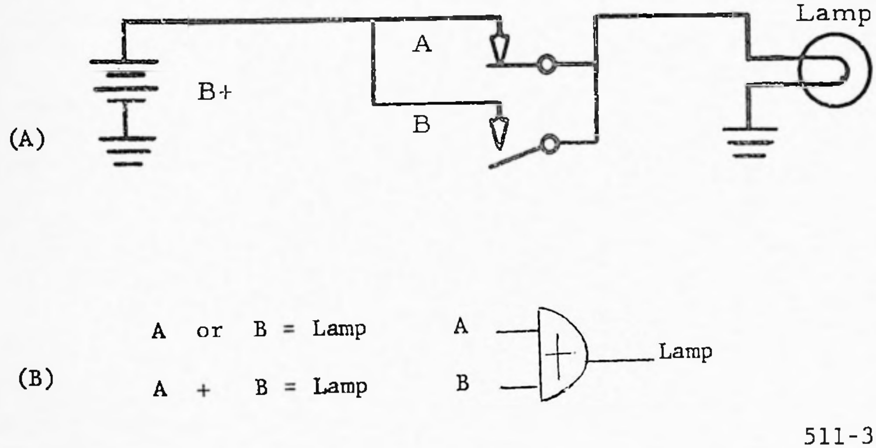


Figure 33. The "OR" circuit.

64. THE SERIAL COUNTER

a. Using the theory that has been developed, the subject of serial adders will now be discussed. A group of three flip-flops will be used to show counting up to the decimal digit seven. Assume that the flip-flops (FF) shown in figure 34 can only be complemented with a pulse that goes in the negative direction. Such a pulse is one which can be obtained when the voltage on the output of a flip-flop drops from positive to zero.

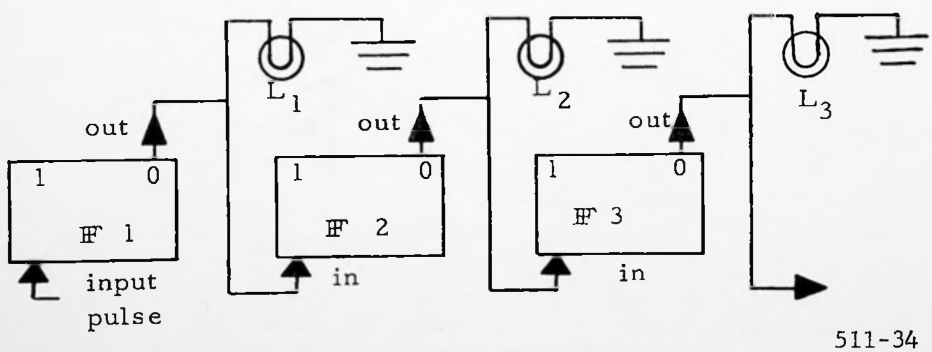


Figure 34. Flip-flop serial adder.

b. Notice in the figure that the output of FF 1 is connected to the input of FF 2, and the output of FF 2 is connected to the input of FF 3. Therefore, when the output of FF 1 drops from positive to zero, FF 2 will be triggered. When the output of FF 2 drops from positive to zero, FF 3 will be triggered. It will be assumed that a 1 on the output of any FF will represent a positive voltage and a 0 will represent a condition of zero volts. In figure 34, all flip-flops are in their zero condition, and L1, L2, and L3 are not lit. The condition of the counter may be written as 000. A negative pulse on the input lead of FF 1 will cause that flip-flop to go to the one state, lighting L1. The condition of the counter is then 100. (In this case, the low order digit will be at the left.) The fact that the voltage rise from zero to positive is seen on the input of FF 2 does not affect FF 2, since only changes in the negative direction influence the state of the flip-flops. A second negative pulse on the input of FF 1 will complement FF 1, causing the voltage at the output of FF 1 to drop from positive to zero. This drop will be seen on the input of FF 2 and will now cause this flip-flop to complement. The condition of the counter is now 0 1 0 (lamps 1 and 3 are off--lamp 2 is on). A third input pulse will turn FF 1 on and leave FF 2 unaffected (no voltage drop seen on the input of FF 2). The condition of the counter is now 110. A fourth input pulse will complement FF 1, which in turn will complement FF 2. Since there is also a voltage drop seen at the input of FF 3 (output of FF 2 dropped from positive to zero), this flip-flop will also be complemented, and the condition of the counter will be 001. The 1 will be the most significant digit. It becomes obvious that succeeding pulses will change the counter to 101, 011, 111. The eighth pulse will reset the counter completely to 000.

65. THE PARALLEL SHIFT REGISTER

a. In computer applications, the ability to shift information from one part of the computer to another is desirable. This information is held in a device called a register and may then be shifted to another register. In the circuit below (fig 35), information may be shifted from the A register (FF 1 and FF 2) to the B register (FF 3 and FF 4). Since each flip-flop can hold one bit of information, we can shift "two bits" of information.

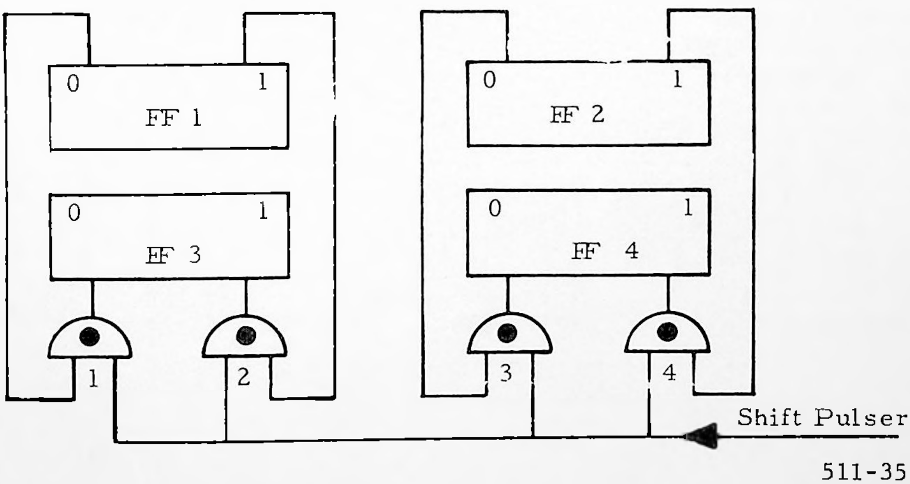


Figure 35. Parallel shift adder.

b. The shift register shown in figure 35 has four "AND" gates associated with the flip-flops. Since an "AND" must have all its inputs on to produce an output, and since each "AND" gate has one of its inputs tied to the shift pulse line, it is obvious that an output may be produced only when there is a pulse present on the shift line. Each "AND" gate is tied to a separate input. "AND's" 1 and 3 are tied to the reset or "zero" lines of FF 3 and FF 4.

c. In figure 35, a "1" condition exists on the output lines of FF 1 and FF 2 which are connected to "AND" gates 2 and 4 respectively. The zero condition lines are tied to "AND" gates 1 and 3 respectively. When a pulse is placed on the shift line, "AND" gates 2 and 4 are turned on and sets FF 3 and FF 4 to the "1" condition. Thus the two bits of information that were in the A register are shifted to the B register.

66. THE PARALLEL ADDER

a. Since all arithmetic operations performed in a computer are done through some form of addition, it is appropriate to take a brief look at the operation of a parallel adder. In binary addition, only four numerical combinations are considered:

	D		A		
(1)	0	+	0	=	0
(2)	0	+	1	=	1
(3)	1	+	0	=	1
(4)	1	+	1	=	0 with 1 to carry

b. Numbers will be taken from the D register (corresponding to the distributor) and added to the number in the A register (corresponding to the accumulator). The circuit in figure 36 represents the parallel adder. FF 1 represents the D register, and FF 2 represents the A register. The input to FF 2 is a complement pulse.

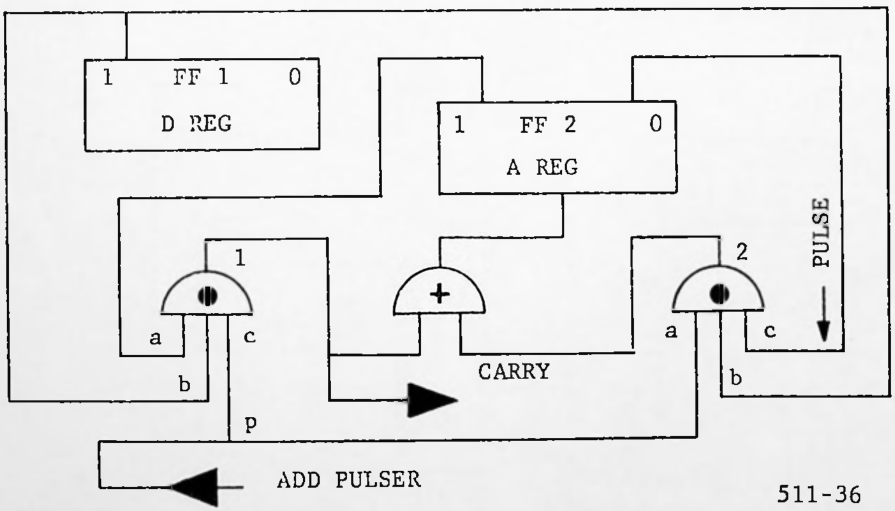


Figure 36. Parallel adder.

c. By examining the four combinations above, we can see how the parallel adder operates. Assume that the left side of each flip-flop must be positive for a "1" condition to exist.

(1) In the first combination, the D and A registers are both zero. In this case, a zero voltage would exist on lines a, b, and c of "AND" gate 1, and on lines a and b of "AND" gate 2. A pulse on the add

line would change line c of both "AND" gates to a positive condition. However, there would still be no output on either "AND" gate due to the remaining zero inputs.

(2) In the second situation, the "D" register is "zero" and the "A" register is in a "1" condition. A pulse on the add line will still leave line b on both "AND" gates in a zero condition and "A" register will remain a one.

(3) In the third situation, the "D" register is "one," and the "A" register is in a zero position. With a pulse on the add line, "AND" gate 2 will be on (the right side of FF 2 shows a positive potential), and FF 2 will receive a complementing pulse through the "OR" circuit. This will flip FF 2 so that a positive potential will be seen on its left side.

(4) In the last situation, the "D" and "A" registers are both in the "1" condition. A pulse on the add line will now turn "AND" gate 1 on, will reset FF 2 to the zero condition, and produce a carry at the output of gate 1.

APPENDIX

GLOSSARY OF ADPS TERMS

This glossary is a compilation of terms you will encounter throughout your studying of ADPS. It is provided as an aid in becoming familiar with the language of automatic data processing.

ACCESS, RANDOM. Access to information stored under conditions in which sequencing of input data is not required.

ACCESS TIME. The amount of time required to locate or call a character of data from its storage position and make it available for processing or to return a character from the processing unit to its storage location.

ACCUMULATOR. A register in the arithmetical logical unit where the results of arithmetical or logical operations are first produced. (See REGISTER.)

ADDRESS. The specific location where data is stored, or a symbol, or a numerical or alphabetical character designating the storage location of data or a machine unit to be used.

APPLICATIONS STUDY. The detailed process of designing a system or set of procedures for using electronic digital computers for definite functions or operations and establishing specifications for equipment suitable to the specific needs, known also as an engineering study.

ARITHMETIC OPERATION. An operation in which numerical quantities form the elements of the calculation; e.g., addition, subtraction, multiplication, division.

ARITHMETIC UNIT. That part of a computer which performs arithmetic operations.

AUTOMATIC DATA PROCESSING EQUIPMENT (ADPE). Includes digital or analog computers (input, storage, computing, control, and output) and the auxiliary equipment which directly supports the computers (except communications equipment).

AUTOMATIC DATA PROCESSING SYSTEMS (ADPS). An integrated relationship of components alined to establish proper functional continuity toward the successful performance of defined task or tasks, using automatic data processing equipment (ADPE) as a principal means of processing the data.

AUTOMATION. The entire field of investigation, design, development, application, and methods of rendering or making processes or machines self-acting or self-moving; rendering automatic; theory, art, or technique of making a device, machine, process, or procedure more fully automatic; the implementation of a self-acting or self-moving (hence, automatic) process or machine.

AUXILIARY EQUIPMENT. See AUTOMATIC DATA PROCESSING SYSTEM.

BAND. A group of recording tracks on a magnetic drum, disk, or tape.

BASIC RECORD. A record that is maintained for day-to-day operation and administration; for example, a stock record card.

BINARY CODE. A coding system in which successive digits, reading from right to left, are interpreted as successive powers of the base 2, instead of being interpreted as powers of the base 10 as in the decimal system.

BIT. See DIGIT, BINARY; a contraction of binary digit.

BLOCK. A group of words considered or transported as a unit; an item; a message; in flow charts, an assembly of boxes, each box representing a logical unit of programing, usually requiring transfer to and from the high speed storage.

BLOCKED RECORDS. A group of consecutive information units maintained together in order to conserve space on a magnetic tape and to provide faster reading and writing.

BRANCHING. The logical means of recognizing one of two or three possible conditions.

BREAKPOINT. A point in a routine at which the computer may, under the control of a manually set switch, be stopped for a visual check of progress.

BUFFER. A storage device used to compensate for a difference in rate of flow of information or time of occurrence of events when transmitting information from one device to another. An "addressable buffer" is a buffer with an address to permit selective handling of data within the buffer.

BUSINESS-TYPE OPERATION. General identification of those functions that involve the handling of supply, personnel, financial, accounting, production control, and statistical data.

CALCULATING. The application of a mathematical process, usually arithmetical, to data. Calculation creates new data in the processing routine.

CALL NUMBER. A set of characters identifying a subroutine and containing information concerning parameters to be inserted in the subroutine, information to be used in generating the subroutine, or information related to the operands; a call word when exactly one word is filled.

CARD-TO-TAPE. The process of transferring, in machine language, data from punched cards to punched paper tape or magnetic tape.

CHARACTER. One of a set of elementary symbols, such as those corresponding to the keys on a typewriter (symbols may include the decimal digits 0 through 9, the letters A through Z, punctuation marks, operation symbols, and any other single symbols which a computer may read, store, or write); a pulse code representation of such a symbol.

CHECK. A means of verifying information during or after an operation. A self-checking process performed by the digital computer to test the validity of the machine's computations. Usually composed of several types of checks (parity check, redundancy check, control check, etc.).

CHECK, BUILT-IN OR AUTOMATIC. Any provision constructed in hardware for verifying the accuracy of information transmitted, manipulated, or stored by any unit or device in a computer. Extent of automatic checking is the relative proportion of machine processes that are checked or the relative proportion of machine hardware devoted to checking.

CHECK, PROGRAMED. A system of determining the correct program and machine functioning either by running a sample problem with similar programing and known answer, including such mathematical or logical checks as comparing A times B with B times A, and usually where reliance is placed on a high probability of correctness rather than built-in error detection circuits or by building a checking system into the actual program being run and utilized for checking during the actual running of the problem.

CLASSIFYING. A natural or artificial system, or a mixture of both, identifying items of data. In the natural system, data is identified according to its essential nature; in the artificial system, codes identify data. Basic types of codes include alphabetic, numeric, and alpha-numeric.

CODE. A system of symbols for use in representing rules for handling the flow or processing of information on a computer.

CODE, COMPUTER. The code representing the operations built into the hardware of the computer.

CODE, INSTRUCTION. A system of symbols used as an artificial language for describing or expressing the instructions to be carried out by a digital computer. In automatically sequenced computers, the instruction code is used when describing or expressing sequences of instructions, and each instruction word usually contains a part specifying the operation to be performed and one or more addresses that identify a particular location in storage. Sometimes the address part of an instruction is not intended to specify a location in storage but is used for some other purpose. If more than one address is used, the code is called a multiple-address code.

CODE, MULTIPLE-ADDRESS. An instruction or code in which more than one address or storage location is used. In a typical instruction of a four-address code, the addresses specify the location of two operands, the destination of the result, and the location of the next instruction in the sequence. In a typical three-address code, the fourth address specifying the location of the next instruction is dispensed with, and the instructions are taken from storage in a preassigned order. In a typical two-address code, the addresses may specify the locations of the operands. The results may be specified by another instruction.

CODE, OPERATIONAL. That part of an instruction that designates the operation to be performed.

CODING (NOUN). The list, in computer code or in pseudocode, of the successive computer operations required to solve a given problem.

CODING, ABSOLUTE, RELATIVE, OR SYMBOLIC. Coding in which one uses absolute, relative, or symbolic addresses, respectively; coding in which all addresses refer to an arbitrarily selected position, or in which all addresses are represented symbolically.

CODING, ALPHABETIC. Predetermined abbreviations used in preparing information for input into a computer so that information is reported in the form of letters; e.g., New York as NY; carriage return as CR.

CODING, NUMERIC. A system of abbreviating used in preparing information for machine acceptance by reducing all information to numerical form or codes; in contrast to alphabetic coding.

CODING, SYMBOLIC. Coding in a language other than that which is accepted directly by the computer itself. This type of coding must be mechanically converted to computer language before it can be executed by the computer.

COMMAND. A pulse, signal, or set of signals initiating one step in the performance of a computer operation.

COMMUNICATING. The process of transferring data from one point to another in the processing routine and of bringing the final results to the user's location; the transporting of data. The processing routine may require that data be transported over various distances.

COMPATIBILITY, EQUIPMENT. Ability of one computer system to accept and process data prepared by another system without conversion or code modification.

COMPILER. A program-making routine which produces a specific program for a particular problem in various ways, based on predetermined requirements.

COMPUTER, ANALOG. A calculating machine that solves problems by translating physical conditions like flow, temperature, or pressure into electrical quantities and for using electrical equivalent circuits for the physical phenomena.

COMPUTER, DIGITAL. See AUTOMATIC DATA PROCESSING SYSTEM. In contrast to analog computers, a digital computer uses numbers to express all the variables and quantities of a problem.

COMPUTER, GENERAL-PURPOSE. A computer sufficiently flexible to meet the requirements of general business-type data processing activities.

COMPUTER, SPECIAL-PURPOSE. A machine usually with built-in instructions rather than flexible stored programs that can be changed at will; built to do a specific job, or possibly two or three closely related jobs; not suited for functions other than the specific jobs.

CONSOLE. The unit of an ADPS that exercises master control over operations of the system. It is the means by which the operator can communicate instructions to, or obtain information from, any element of the system.

CONVERTER. A unit that changes the language of information from one form to another to make it available or acceptable to another machine; e.g., a unit that transcribes information from punched cards to magnetic tape, possibly including editing facilities.

CORE, MAGNETIC. A magnetic material capable of providing storage, gating, or switching functions, usually of doughnut shape, and pulsed or polarized by electric currents carried on wire wound around the material.

DATA. Particles of information; pieces of intelligence. Though plural in form, the word "data" is often used in the singular.

DATA PROCESSING. The preparation of source documents that contain basic elements of information and the handling of such data (classifying, sorting, calculating, summarizing, recording, and communicating) to produce records and reports.

DATA PROCESSING AREAS. A grouping of related activities into major classifications; such as item accounting, financial inventory accounting, cost accounting, and civilian payroll.

DATA TRANSMISSION EQUIPMENT. See AUTOMATIC DATA PROCESSING SYSTEM.

DEBUG. To isolate and remove all malfunctions from a computer or all mistakes from a program routine.

DIAGRAM. A schematic representation of a sequence of routines and subroutines designed to solve a problem; a coarser and less symbolic representation than a flow chart, frequently including descriptions in English words.

DIGIT. One of the ten decimal digits; i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.

DIGIT, BINARY. A whole number in the binary scale of notation. This number may be either 0 (zero) or 1 (one). It may be equivalent to an "on" or "off" condition, or a "yes" or a "no."

DOWNTIME. The period during which a computer is malfunctioning or not operating correctly due to machine failure; contrasted with available time, idle time, or standby time.

DRUM, MAGNETIC. A rotating cylinder containing a magnetic material coating on which information may be stored.

ELECTRONIC. Pertaining to the application of that branch of science which deals with the motion, emission, and behavior of currents of free electrons, especially in vacuum, gas, or photo tubes, and special conductors or semiconductors. Electronic is contrasted with electric, which pertains only to the flow of large currents in wires.

ELEMENT OF DATA. A specific item of information appearing in a set of data; e.g., quantity of a supply item issued, unit rate, amount, and balance on hand.

EQUIPMENT, CONVERSION. Equipment that is capable of transposing or transcribing the information from one data processing medium to another data processing medium; e.g., converting punched cards to magnetic tape.

EQUIPMENT, INPUT. Equipment by which an operator either introduces directly or transcribes original data and instructions to a medium that may be used in an ADPS.

EQUIPMENT, OUTPUT. Any device of an ADPS that transcribes information from within the system to a form for use outside the system.

ERASE. To replace all the binary digits in a storage device by binary zeros or other signs (varies with equipment). In a binary computer, erasing is equivalent to clearing, while in a coded decimal computer, where the pulse code for decimal zero may contain binary ones, clearing leaves decimal zeros while erasing leaves all-zero pulse codes. Erasing is the process of demagnetizing magnetic tape to permit reuse.

ERROR. The amount of loss of precision in a quantity; the difference between an accurate quantity and its calculated approximation (errors occur in numerical methods; mistakes occur in programing, coding, data transcription, and operating, malfunctions occur in computers and are due to physical limitations on the properties of materials); the differential margin by which a controlled unit deviates from its target value.

FEASIBILITY STUDY. The preliminary process of determining the overall soundness of applying an ADPS.

FIELD. A set of one or more characters which is treated as a whole; a set of one or more columns on a punched card consistently used to record similar information.

FINAL REPORT. The end product of a data processing system at a given installation. No data for further processing at the same installation is ever generated by a final report.

FLIP-FLOP. A bistable device; a device capable of assuming two stable states; a bistable device that may assume a given stable state, depending upon the pulse history of one or more input points and having one or more output points. The device is capable of storing a bit of information, controlling gates, etc.

FLOW CHART. A graphical representation of a sequence of operations of paper flow, using symbols to represent the operations; such as sort, compute, substitute, compare, jump, copy, read, write, etc.

HARD COPY. Information in finished and readable form, appearing as a printed page and readily usable without further processing.

HARDWARE. The components and devices forming a computer system.

HEAD. A device that reads, records, or erases information in a storage medium; usually a small electromagnet used to read, write, or erase information on a magnetic drum, disk, or tape or the set of perforating or reading fingers and block assembly for punching or reading holes in paper tape.

INPUT. The information which is transferred from external storage into internal storage; a modifying term to designate the device performing this function.

INSTRUCTION. A set of characters that defines an operation to be performed by the computer.

INTEGRATED DATA PROCESSING. The multiple use of source data to provide management with the desired end products in one uninterrupted sequential operation.

INTERMEDIATE RECORD. A record that is maintained as a means of deriving data for further processing. Example: a financial journal, from which a ledger is posted, or a worksheet.

LANGUAGE, MACHINE. Information recorded in a form capable of being interpreted by a computer; information which can be sensed by a machine.

LIBRARY ROUTINE. An ordered set or collection of standard and proven routines and subroutines by which problems and parts of problems may be solved, usually stored in relative or symbolic coding. (A library may be subdivided into various volumes, such as floating decimal, double-precision, or complex, according to the type of arithmetic employed by the subroutines.)

LOCATION. A memory position in which a computer word or character is stored.

MEMORY. See STORAGE.

MICROSECOND. A millionth part of a second (.000001).

MILLISECOND. A thousandth part of a second (.001).

MODIFY. To alter one of the instruction addresses before continuing with the program.

NUMBER SYSTEMS. The representation of quantities by a positional value system. Commonly used bases are shown with an asterisk.

Base	Name	Base	Name
2	Binary*	10	Decimal*
3	Ternary	12	Duodecimal*
4	Quarternary, Tetral	16	Hexadecimal*, Sexidecimal
5	Quinary	32	Duotricenary
8	Octal*	2, 5	Biquinary*

OFF-LINE OPERATION. Distinguished from on-line in that data can be processed as a separate operation without interfering with the main computer.

ON-LINE OPERATION. A type of system application in which the medium for producing output data is connected directly to the computer.

OPERAND. Any one of the quantities entering or arising in an operation. An operand may be an argument, a result, a parameter, or an indication of the location of the next instruction. Usually an operand is a factor that is used to produce a result.

OUTPUT. Information transferred from the internal storage of a computer to secondary or external storage; information transferred to any device exterior to the computer.

PARAMETER. In a subroutine, a quantity that may be given different values when the subroutine is used in different main routines or in different parts of one main routine but that usually remains unchanged throughout any one such use; in a generator, a quantity used to specify input-output devices to designate subroutines to be included or otherwise to describe the desired routine to be generated.

PROCEDURE. A predetermined course of action which governs and prescribes the operations (manual and mechanical) making up the system. The procedure establishes who does what, where, when, and in what sequence.

PROGRAM. A plan for the solution of a problem. A complete program includes plans for the transcription of data, coding for the computer, and plans for the absorption of the results into the system (the list of coded instructions is called a routine); to plan a computation or process from the asking of a question to the delivery of the results, including the integration of the operation into an existing system. Thus, programing consists of planning and coding, including numerical analysis, systems analysis, specifications of printed formats, and any other functions necessary to the integration of a computer in a system.

PROGRAMER. The individual who prepares the program.

PROGRAMING. The process of reducing the data handling procedure and the data itself to a form that can be utilized by the processing equipment. Programing can be divided into two steps: (1) Structuring the new procedure in terms of precise logical sequence and (2) coding this data for the computer.

PROGRAMING, AUTOMATIC. Any technique in which the computer is used to help plan as well as code a problem; e.g., compiling routines; interpretive routines.

PROGRAMING, OPTIMUM. The production of the most efficient program for the best use of available computer time.

PSEUDOCODE. An arbitrary code, independent of the hardware of a computer, which must be translated into computer code.

PUNCHED CARD MACHINES (PCM). Electrical, mechanical, or electronic machines which primarily create punched cards or are primarily actuated by them to create punched cards, process data, and/or produce printed reports. Punched card machines are designed on a single functional basis and generally lack the overall logic and computational ability of the electronic computer, although some PCM employ electronic circuitry.

PUNCHED CARD MACHINE SYSTEMS (PCMS). An integrated relationship of components alined to establish proper functional continuity toward the successful performance of a defined task or tasks, using punched card machines (PCM) as a principal means of processing the data.

RADIX (BASE). See NUMBER SYSTEMS.

READ. To copy, usually from one form of storage to another, particularly from external or secondary storage to internal storage; to sense the presence of information on a recording medium.

REAL TIME. Processing the data at the same time a physical process creates the data in order that the results of the processing may be useful to the physical creative process itself.

RECORD (NOUN). A listing of information, usually in printed or printable form; one output of a compiler consisting of a list of the operations and their positions in the final specific routine and containing information describing the segmentation and storage allocation of the routine.

RECORD (VERB). To copy or set down information in reusable form for future reference; to make a transcription of data by a systematic alteration of the condition, property, or configuration of a physical medium; e.g., placing information on magnetic tape or a drum in the form of magnetized spots.

REGISTER. The hardware for storing one or more computer words wherein the results of arithmetical or logical operations become available. Registers are usually zero-access storage devices; i.e., data which is immediately available.

RERUN. To repeat all or part of a program on a computer, usually occasioned by a malfunction of the computer, program mistake, or operator error.

ROUTINE. A set of coded instructions arranged in proper sequence to direct the computer to perform a desired operation or series of operations.

RUN. One performance of a program on a computer; performance of one routine or several routines automatically linked so that they form an operating unit during which manual manipulations are not required of the computer operator.

SEGMENT. To divide a routine into parts, each part consisting of an integral number of subroutines, capable of being completely stored in the internal storage, and containing the necessary instructions to jump to other segments; in a routine too long to fit into internal storage, a part short enough to be stored entirely in the internal storage and containing the coding necessary to call in and jump automatically to other segments. Routines which exceed internal storage capacity may be automatically divided into segments by a compiler.

SELECT. To designate one of a number of possible alternates.

SELECTOR. A device that interrogates a condition and initiates a particular operation according to the interrogation report.

SEQUENTIAL ACCESS. Desired data located by searching in sequence through all locations, until the desired location is found. Magnetic tape is a good example of this type of access.

SET OF DATA. A document containing one or more elements of data.

SHIFT. To move the characters of a unit of information columnwise right or left. For a number, this is equivalent to multiplying or dividing by a power or the base of notation.

SORT. To arrange items of information according to rules dependent upon a key or field contained in the items.

SORTING (SEQUENCE CHART). The segregation of sets of data into classes, categories, or sequence for the purpose of facilitating subsequent processing operations.

SOURCE DOCUMENT. The document of original entry from which basic data is extracted for conversion, where necessary, and entered into the data processing system; for example: special orders; DD Form 689, Individual Sick Slip; DA Form 1049, Personnel Action; and DA Form 1546, Request for Issue or Turn-in.

STORAGE. Any device into which units of information can be copied, which will hold this information and from which the information can be obtained at a later time; devices, such as plugboards, which hold information in the form of arrangements of physical elements, hardware, or equipment; the erasable storage in any given computer.

STORAGE, BUFFER. A synchronizing element between two different forms of storage; an input device in which information is assembled from external or secondary storage and stored ready for transfer to internal storage; an output device into which information is copied from internal storage and held for transfer to secondary or external storage, including on-line printers. Computation continues while transfers between buffer storage and secondary or internal storage or vice versa take place.

STORAGE, ELECTROSTATIC. A device possessing the capability of storing changeable information in the form of charged or uncharged areas on the screen of a cathode-ray tube.

STORAGE, MAGNETIC. Any storage system that uses the magnetic properties of materials to store information; e.g., magnetic core.

STORAGE, TEMPORARY. Internal storage locations reserved for intermediate and partial results.

STORE. To transfer an element of data to a device from which it can be obtained later in an unaltered form.

SUBROUTINE. The set of instructions necessary to direct the computer to carry out a well-defined mathematical or logical operation; a subunit of a routine. A subroutine is often written in relative or symbolic coding even when the routine to which it belongs is not.

SUMMARIZING. The compression of a body of data into more concise form. Summarizing aids in the reconstruction of data and is not far removed from sorting or calculating; however, there are distinctions. Sorting merely achieves a separation--usually a meaningless one until the results of the separation are summarized. Calculating is a mathematical process in which the objective is a mathematical result. Summarizing may occur as an incident of calculating, but it is not the primary purpose of calculating. Summarizing may occur at various stages of the processing routine. It also creates new data.

SYSTEM. An assembly of components united by some form of regulated introduction; an organized whole.

SYSTEMS ANALYSIS. The study, analysis, and improvement of the systems which service, control, and coordinate all the operations of an organization; the segmentation of such systems into components, the determination of the feasibility of applying ADPS to any of these components, and the systems design of the selected components to accommodate the capabilities of electronic digital computers.

SYSTEMS ANALYST. An individual who performs systems analysis.

TAPE, MAGNETIC. A tape or ribbon of any material impregnated or coated with magnetic material (usually ferrous oxide) on which information may be recorded in the form of magnetically polarized spots.

TAPE, PERFORATED. A punched paper tape with a capacity of from 5 to 8 channels and a density of approximately 10 characters per inch, generally produced by office machines as a by-product secured during the preparation of a source document and used as an input-information-gathering medium for further ADPS processing. Also, when used for transmission purposes, the tape can be prepared from punched cards which, in many instances, are the source documents.

TAPE-TO-CARD. The process of transferring information from paper tape or magnetic tape to punched cards.

TIME, IDLE. Time in which any item of equipment, in good operating condition, is not in use on a problem.

TRANSFER. To copy, exchange, read, record, store, transmit, transport, or write data; to change control; to jump to another location.

WORD. A set of characters which occupies one storage location, is treated by the computer circuits as a unit, and is transported as such. Ordinarily, a word is treated by the control unit as an instruction and by the arithmetic unit as a quantity. Word lengths are fixed or variable, depending upon the particular computer.

WRITE. To transfer information to an output medium; to copy, usually from internal storage to external storage; to record information in a register, location, or other storage device or medium.