DIGITAL COMPUTER BASICS

PREPARED BY THE BUREAU OF NAVAL PERSONNEL

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PREFACE

This training course is intended for use by U. S. Navy and Naval Reserve personnel whose duties require an elementary and general knowledge of the fundamental concepts of electronic computers and data processing, and as an introductory course for those aspiring to the Data Systems Technician rating.

The coverage of the five basic sections of a computer are treated in sufficient detail to equip the reader with a knowledge of the circuits and functions peculiar to each section and to show how these sections are related. Programming techniques are treated in three chapters. Part I presents a definition of terms, the procedure for stating the problem, and the development of flowcharts. Part II builds on the previous chapter and concludes by showing how the problem is converted into actual computer (machine) language. Part III describes the conversion of a mnemonic language to machine language as accomplished through the use of compilers. Other subjects treated include: Number Systems, Boolean Algebra, Analog-Digital and Digital-Analog Conversions, and Diagnostic Maintenance Routines.

As one of the Navy Training Courses, this book was prepared by the Training Publications Division of the Naval Personnel Program Support Activity, Washington, D. C., for the Bureau of Naval Personnel.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

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At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

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The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

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Never have our opportunities and our responsibilities been greater.

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Chapter 1

INTRODUCTION TO DATA PROCESSING

The technological advances made in data processing systems in the past decade are astonishing. The reasons for these advances are twofold. With each system development there arises new applications of the system, and with each new system application, an insight to further developments is realized. Consequently, the sophistication of the system and the boundless applications of data processing systems, mutually contribute to the development of new and improved systems.

Originally, machines are designed and built to meet specific needs. A newly engineered machine usually increases productivity or quality, and decreases production time. It may simplify the process although this is not a requirement.

The data processing concept is not new. In fact it was perceived more than a century ago. Recent advances in data processing systems have been, and are being motivated by the need for faster and more efficient ways of processing large quantities of data. Considering the rate of population increases, the rising ability of manufacturers to produce more materials for our comfort and use, the complexities of our military operations, and our continued advance toward greater ideals, it is easy to see that data processing systems will become more and more involved in all phases of our civilization.

For example, modern communications, radar, and missile equipments depend almost entirely on the ability of data processing equipments to perform calculations and provide updated and accurate control information. So dependent are these equipments on data processing systems (particularly the computer) that they are rendered completely useless if the controlling data processing system fails. Nevertheless, because of the high reliability of the controlling systems, and too, because of the ability of the systems to provide instant and accurate control of all operations simultaneously, it is expected that electronic systems such as these will become automated to an even greater extent in future years.

SCOPE OF THIS COURSE

Digital Computer Basics, NavPers 10088, is intended for use as a basic reference for all Navy personnel whose duties require them to have a knowledge of the fundamentals of electronic data processing. It presents a coverage of the basic concepts of computers and automatic data processing. Emphasis is placed on logic functions and the theory of operation of representative data processing circuits and components. Detailed treatments of specific equipments will not be considered in this text.

A knowledge of basic mathematics and basic electricity and electronics (equivalent to that derived by completing correspondence courses based on Basic Electricity, NavPers 10086; Basic Electronics, NavPers 10087; and Mathematics, Vol. 1, NavPers 10069-C), is necessary before the student can expect to comprehend the material presented in this course.

This course begins (a little bit later in this chapter) by presenting some background information and introductory concepts of data processing systems. Following the introductory chapter (in chapters 2 and 3), a treatment of number systems and Boolean Algebra is presented so that an understanding of computer logic and symbology can be attained prior to any consideration of the actual internal operation of computer circuits.

The treatment of the Control Unit (Ch. 4), the Arithmetic Unit (Ch. 5), the Memory and Storage Unit (Ch. 6), and the Input/Output Unit (Ch. 7) presents basic operations of these computer sections and their interrelationships, and some of the circuits commonly used in each of these sections. A thorough knowledge of the contents of these chapters is essential to an understanding of the programming concepts presented in chapters 8, 9, and 10.

The principles of programming are presented in three parts. Part I treats basic concepts. Part II establishes the characteristics and assumes a repertoire of instructions for a hypothetical computer. It explains how the computer interprets the instructions and operates using machine language. Part III explains the purpose and uses of compilers.

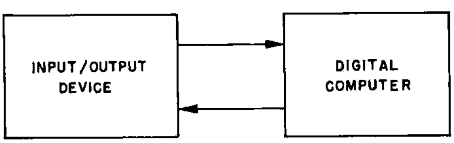
Because digital computers are used in many applications to solve problems concerning analog data, it is necessary to convert the analog input to digital data. A consideration of the basic principles of analog-to-digital conversions is presented in chapter 11.

The text concludes by showing how diagnostic maintenance routines (maintenance programs) are used to isolate malfunctions in a data processing system.

PROCESSING OPERATIONS

Data processing (fig. 1-1) is the process of collecting data (from an input source), manipulating them according to a set of rules (within the computing device), and providing a useful output at the output device. (For the purpose of this discussion, it can be assumed that the input/output device is a teletypewriter.) Any system which performs this set of operations is a data processing system. A more elaborate system can be constructed by first, adding more input/output devices, and second, by adding one or more additional digital computers.

There are many such data processing systems in present use in the Navy. Navy supply personnel use a data processing system to maintain proper inventories in the supply system. A data processing system is used to compute pay at Navy Finance Centers. Maintaining



164.1
Figure 1-1.—Basic Data Processing System.

the air plot in CIC is a data processing operation. The little black book one uses to keep track of expenses is part of a data processing system.

In data processing, data are converted into information. This statement may seem odd at first because in ordinary usage, the two words "data" and "information" mean the same thing. With reference to data processing, however, the words "data" and "information" do not have the same meaning. "Data" means the mass of facts about a single subject, and "information" means the desired content of the data.

To illustrate the difference between information and data, consider the following example. The list of all parts in a storeroom (listed by stock number, number on hand, and allowance of each item) is an example of a mass of data. The list of items that should be requisitioned to fill the storeroom to the allowance level is an example of information. The process of extracting the information (items to be ordered) from the data (items on hand and allowance) is data processing. The procedures and equipments that will accomplish the desired operations constitute a data processing system.

All data processing, regardless of the facilities actually used, require three fundamental operations:

1. Collection of data
2. Manipulation of data
3. Production of useful output

COLLECTION OF DATA

The first part of any data processing operation is the collection of new data. Before any processing can be done, data must be "captured." Since data seldom occurs in a form that a system can use directly, the collection of data usually involves three steps: (1) acquisition; (2) conversion; and (3) verification.

Acquisition

Data may exist in a variety of initial forms. It may be in the form of the number of like items in a bin, a blip on a radar indicator (PPI-scope), or the time clock punches on a time card.

To find the quantity on hand of a particular item, the storekeeper counts these items. To establish an air contact the radarman watches a spot of light on a scope. To total the number of hours a man worked in a week the timekeeper notes when the man punched in and out each day of the week. All of the operations involve the acquisition of data.

Conversion

The acquired data may not always be in a form usable by the computer device. Therefore the data must be converted to a form suitable for processing by the computer. In the first analogy, the storekeeper writes the item stock number and the item count number, thereby converting a mental item count to a permanent record. This record is his usuable form of data. The radarman notes the range and bearing of a contact blip, and records it. In this analogy, the range and bearing notation is his usuable form of data. To obtain his usuable data, the timekeeper notes the time of arrival and departure of the worker for each day of the week, adds the number of hours worked and thereby ascertains the number of hours for which the man should be paid. All of these conversion operations involve changing of the initial data to a more usable form which, as one can see, is dependent on the particular application and situation.

Verification

In the collection of data, the acquisition and conversion steps serve no purpose if an error has been introduced. Therefore it is necessary to make certain that the acquired data is valid. In the case of the storekeeper, he may count the items in the bin twice to make certain his count is correct; the radarman may check his initial contact within a few seconds, and then double check the range and bearing; and the timekeeper may cross check his computations to ensure their accuracy. Similarly, these conceptual procedures, which are intended to eliminate the possibility of introducing erroneous data into the data processing system, are part of verification.

MANIPULATION OF DATA

The manipulation portion of a data processing system includes all operations which use collected data to provide output information. All manipulations may be grouped into two operations: (1) rearrangement, and (2) processing.

Rearrangement

Since data seldom appears in a usable arrangement it must be classified and arranged so that it will fit into the system with the least possible amount of "friction." Any operation which changes the sequence of data, or inserts or extracts data without performing any computation, is considered to be rearrangement. Most rearrangement operations fall into one of two categories: (1) classification, or (2) sequencing. Classification is the process of grouping data items which are alike. Sequencing is the process of placing data items into some desired sequence.

Processing

The processing operation consists of those operations which directly involve the extraction of information from a mass of data. More specifically, operations which actually produce a desired output by means of arithmetic computations within the computing device are considered to be processing operations. In electronic data processing systems, which are our prime consideration in this text, these operations are accomplished by an electronic computer.

PRODUCTION OF USEFUL OUTPUT

The third part of any data processing operation is the output. Everything that happens in the system is aimed at providing the output. In any system there are usually several distinct outputs. Some of the outputs of the inventory maintenance system discussed earlier are: (1) requisitions to replenish stock; (2) an accurate list of the actual contents of the storeroom; and (3) activity information (turnover rate) about each item. Other systems may have more sophisticated outputs such as map displays or paychecks. The output is the reason for the existence of the data processing system.

In summary, all data processing systems have three operations: (1) data collection; (2) manipulation of the data; and (3) output. The overall function of any data processing system is to collect masses of data and provide useful information from the data. Data collection usually involves data acquisition, data conversion, and verification. Manipulation involves rearrangement and processing. Output is the actual provision of the information that is desired from the system.

We have examined what a data processing system accomplishes. In this text we will examine the equipments which make up data processing systems and their relationships. When beginning the study of a new system, an initial effort to determine the devices which collect data, those which manipulate the data, and those which provide the output is time well spent. No matter how complex the system is, these general concepts are applicable.

CONCEPTS OF THE HUMAN PROCESSOR

The oldest and still most common data processor is man. In fact, man is still the most efficient data processor if size, mass, and power consumption are used as the criteria. The input to the human data processor is mostly through the eyes and ears. His memory (brain) stores data to be processed and the instructions for processing the data. His brain also functions as the arithmetic and logic element and as the control element. The output can be verbal, written, a physical action or a decision not to act.

Taken in perspective, the human being is the most versatile data processor. He has the ability to interpret his instructions in such a way that they will cover situations that were not explicit in the original form of the instructions. This, by the way, is not an ability inherent in the electronic data processor.

Human Auxiliary Equipment

Although man is a versatile data processor, he has some rather serious shortcomings. His memory capacity is rather limited (on a given subject). He is also unreliable. When called upon to remember large quantities of data, he has an annoying tendency to forget details. His calculating ability is quite limited. The average person, using only his mind, is unable to perform a series of simple calculations. Unaided, man is rather slow in performing the simplest data processing operation.

In addition, man is unreliable when performing repetitious operations. Most data processing operations are repetitious, i.e., the same basic operation is performed many times using different pieces of data. Man's ability to think tends to interfere with his performance of these boring operations. Thus, although man is a remarkable data processor, he needs some auxiliary equipment if he is to be part of an efficient data processing system.

Records

The first aid to data processing developed by man was the keeping of records. The term "record" is meant in the broadest possible sense. Recording is the process of storing data in a medium in such a way that it may be retrieved for use at a later time. Numbers, letters, and symbols were all developed for the recording of data. Once a piece of data is recorded it can be dropped from one's mind so that the memory can be used for other operations. He can recover the recorded data at any time merely by referring to the record.

Any data recording medium can be classified as being one of two main types: (1) temporary storage, or (2) long term storage. Scratch paper and the chalkboard are examples of temporary storage; ledgers and files are examples of long term storage. The technique of recording data has greatly increased man's capacity as a data processor.

Calculating Devices

After recording, the next aid to data processing was the development of calculating devices to relieve man of some of the tedious chores of arithmetic. The abacus, slide rule, and desk calculator are all calculating aids. In addition, each of these devices incorporates a form of data storage, i.e., the results of any operation are available in the device for use in the next calculation.

To illustrate the use of some of these data processing aids, let's examine a part of the process of computing a worker's pay. Assume that some processing has already been done and a clerk has a list of the hours each worker actually worked on each day of the pay period. The clerk has plenty of scratch paper and a desk calculator to use as aids in data processing.

First, the clerk clears the calculator to eliminate any data remaining from a previous operation. He then reads the time from the list (a record), enters it into the keyboard of the calculator (a storage medium), and presses the add button. The calculator adds the number in the keyboard to the previous sum (zero, stored in the gears of the calculator) and retains the new sum in the gear arrangement (a storage medium). The clerk repeats the operation until he has entered all of the time periods into the calculator. At that time, the calculator will be indicating the total number of hours the worker actually worked during the pay period. The clerk records this for future reference and then transfers the worker's wage

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scale from the list to the keyboard and presses the multiply key. The desk calculator performs the calculation and indicates a number which represents the worker's gross pay. The clerk enters this into a record for use in later computation. The clerk then repeats the whole operation for the next worker. The storage media (paper), keyboard, gears in the calculator, etc., relieve the clerk of the chores of having to remember a mass of data. The desk calculator relieves him of all of the routine arithmetic. The clerk's actions have been reduced to transferring data from one medium to another at the right time and pressing the right button on the desk calculator at the right time. The clerk's mental abilities are therefore freed to accomplish more important operations. The clerk's memory is now used for three functions: (1) very short term storing during the transfer of data from one source to another; (2) storage of the plan for processing the data; and (3) deciding what to do at any given time to implement the data processing plan.

DATA PROCESSING PLANNING

Examining the specific operations performed by the pay clerk, it is seen that he executes a set of steps which are a part of a larger, already developed payroll plan. His particular actions in the plan may be described as the "Develop and Store Gross Pay" process, and may be expressed in steps as follows:

Step 1. Get time sheets

Step 2. Pick up top sheet

Step 3. Press "clear" button on calculator

Step 4. Read number from sheet and enter into keyboard

Step 5. Press "add" button

Step 6. Any more time on this sheet?
- a. Yes: go back to step 4
- b. No: go to step 7

Step 7. Read total hours from calculator and write it on paper

Step 8. Read wage scale from list and enter into keyboard

Step 9. Press "multiply" key

Step 10. Read gross pay from calculator and write it on paper

Step 11. File time sheet just used

Step 12. Any more time sheets to be processed?
- a. Yes: go back to Step 2
- b. No: go to Step 13

Step 13. Stop. Request more work.

In data processing terminology, this list of instructions is referred to as a type of "program". The program is a major part of any computing process. However, the operation is rarely this simple and the problem is usually laid out in generalized logical steps. These generalized steps are arranged to form a "flow chart" as shown in figure 1-2. The details of flow charting and programming are treated in later chapters.

MACHINE DATA PROCESSING

Before data can be processed by machine it must be in a form that can be stored, transferred, and manipulated by mechanical and electrical methods. The forms taken by data are the basic determining factors in the actual design of data processing machinery. The actual representation method used in a particular situation is usually determined by the desired rate of handling the data. The data handling rate may vary from a few pieces of data per second to many million pieces of data per second in the same system.

Data Representation Methods

Any data representation method has three main aspects: (1) the storage medium; (2) the writing method; and (3) the reading method. The storage medium is the physical material in which data is actually held. The writing method is that technique whereby data is impressed into the storage medium. Usually the three aspects are so closely connected that it is difficult to separate them.

Storage Medium

A variety of storage media have appeared throughout history. Stone, clay, and wood were used many thousands of years ago as data recording media. Paper, cardboard, and plastic have come into common use in the last hundred years. The latter group has the advantages of easier writing and portability over the former, but the materials aren't quite as rugged.

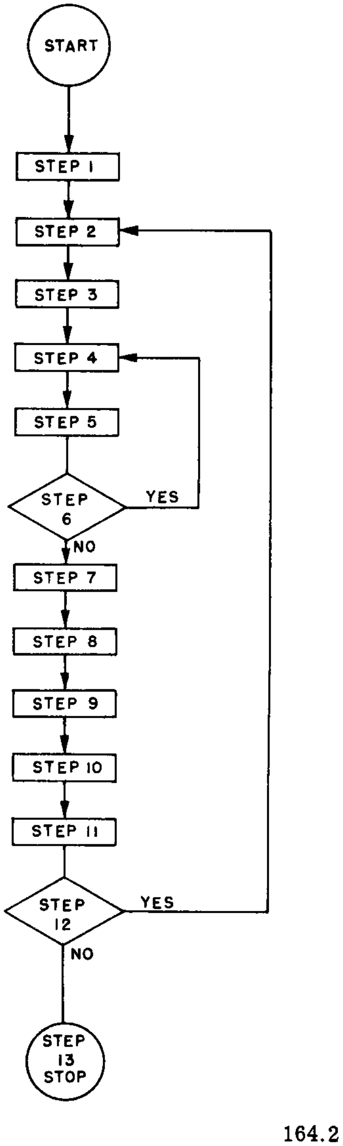

Figure 1-2.—Basic Flow Chart.

Since the advent of machine data processing, several new media have come into use, such as magnetic materials and transistors.

Writing Operation

The writing operation has two components: (1) the actual writing instrument; and (2) the element controlling the operation of the instrument. The physical configuration of the writing instrument is determined by the physical characteristics of the storage medium, while the physical configuration of the control element is determined by the manner in which the data is to be impressed on the medium. Instruments for writing include brushes, pencils, type, and electrical currents. The control element may be the training of a human being, but in electronic data processing it may be the hardware of a machine.

Reading Operation

The reading operation also has two components: (1) the detection of data in the storage media; and (2) the translation of detected data. Data detection schemes vary from recognition of complex symbols to the detection of the presence or absence of a single quantity. The subject of translation will be discussed in more detail at a later time.

MACHINE DATA REPRESENTATION METHODS

The basic method of representing machine processable data is quite different from the method used to represent data that is to be processed by human beings. An alert person is capable of recognizing small differences in data that may indicate great differences in exactly what is being represented. For example, such a person has no difficulty recognizing the difference between the letters "B" and "P", although the physical difference is very small. A machine could be constructed that is just as discerning, but it would probably be large, complex, and unreliable. Thus, most data representation systems that are to be used in machine data processing require only the recognition of the difference between the presence and absence of a piece of data, and complex pieces of data are encoded into groups of these yes/no pieces of data. This system is called binary information representation.

Electrical devices can be adapted to this two-condition system. Many devices, such as relays and switches are naturally two-condition devices. Vacuum tube and transistor circuits can be designed to operate between two conditions with a high degree of reliability. Magnetic materials may be magnetized or unmagnetized. In data processing devices, these two states are referred to as: one and zero, yes and no, or on and off. The basic unit of data representation is the presence or absence of one of the particular conditions.

Most information storage media used in machine data processing can be grouped into three basic categories:

1. Mechanical
2. Electrical
3. Magnetic

This classification is based on the manner in which the data are actually stored and not on the manner in which reading and writing take place. In the mechanical category, the data are retained in the physical configuration of the medium. In the electrical category, the data are retained in the electrical status of a device. In the magnetic category, the data are retained in the magnetic condition of a material. All three categories of storage may occur in close proximity within the same data processing system.

Mechanical Storage

The most common example of mechanical storage is holes punched into paper or cardboard. Small rectangular cards or long strips of paper (called paper tape) form the medium. The data are written into the medium by punching holes through the medium at certain points. Reading is accomplished by detecting the presence or absence of holes at certain points by mechanical, electrical, or photoelectric means. Punched hole systems are very commonly used as input/output media for electrical data processing systems.

Another common mechanical storage media is the electrical data switch. Information is written into the switch manually. Reading is accomplished by sensing whether the switch is an open or closed path for electrical current. Switches are commonly used as instruction inputs to a data processing system.

Electrical Storage

Electrical storage is one of the methods used when very fast access to data is required. The most common form of electrical storage is the flip-flop. A flip-flop is an electronic circuit with two stable states. Once established in one of its stable states, it will remain in that state until some external action causes it to change to the other state. Flip-flops are commonly used for temporary storage in data processing systems.

Magnetic Storage

Magnetic storage occurs in two main forms: (1) surface storage and (2) internal storage. In both forms, the data are stored in the magnetic state of a high-retentivity magnetic material. Once established in a certain state the material will remain in that state until it is affected by some external influence.

Surface storage is a very common data storage medium. It occurs in two basic configurations: (1) long thin strips of nonmagnetic material with a coating of a magnetic material, called magnetic tape; and (2) metal cylinders with a coating of magnetic material, called a magnetic drum. Magnetic tape is commonly used as large capacity, slow access auxiliary data storage. The magnetic drum is used as a medium capacity, fast access data storage device.

Internal (magnetic core) storage has the fastest access time of any of the magnetic data storage media. Magnetic core storage is usually used as the high speed operating storage medium of a data processing system. In this medium the data are stored in the direction of magnetization of tiny doughnut-shaped cores made of a magnetic material.

Data Organization and Processing

In a data processing system, the data are stored, transferred, and manipulated so as to form a useful output. The basic data representation form is the binary digit, but representations using these binary digits must be organized into a system intelligible to the computer if any useful work is to be accomplished. Imagine the work that would be required to keep track of the meanings of a billion binary digits of data if this information is without organization or if the organization system fails. Data bits are organized into characters, words, records, and files. Each of these terms represents a level of organization in a data processing system.

Bits (binary digits) are the basic units of characters and are organized into characters. A character is a unique symbol in a data representation system. Numbers, letters, and punctuation marks are familiar examples of data symbols. In data processing a single character may be formed by any number of bits of data depending on the character represented. (If a character in a system consists of N bits, then 2^N different characters may be represented.)

In most data processing systems the basic data unit is the word. For fixed word length computers, characters are formed into groups of a fixed size called words. Transfers and manipulations (internal to the computer and between input and output devices) usually take place using words of data. Each word is a fixed number of characters, each of which consists of a fixed number of bits.

The "record" is the next data representation level above the word level. A record is a group of words, all concerning the same subject. Each word in the record therefore conveys some particular data about the subject of the record.

A file is a group of records all about the same general subject. The file is usually the top organization level in a data processing system. The following example illustrates the uses of bits, words, characters, records, and files as they are used in a representative data processing system. Consider a storekeeper updating his master inventory using a data processing system.

The primary group of data in this data processing system would be called the master file. The master file contains all of the information necessary for maintaining inventory control of the storeroom and is an organization of a large number of records, with one record present for each item carried in the storeroom. Each record would contain a means of identifying that particular record. This identification item is called the key for that record. The key for a record in this system would be the stock number of the item concerned. The file would probably be arranged in an orderly sequence, proceeding from the lowest stock number to the highest stock number.

All records in the file would be organized in the same format, i.e., within each record a given relative position would contain the same information about the subject of the record, in all records of the file. Each record in this system would contain eight words of data as shown in Table 1-1.

Table 1-1. —Organization of a Record

Word No.	Data Classification
1	Stock number (key)
2	Quantity on hand
3	Quantity allowed
4	Reorder level
5	Cost per item
6	Bin location in the storeroom
7	Substitute stock number
8	Usage code

If the storeroom contained items with 50,000 different stock numbers, the master file would contain 50,000 of these eight-word records.

Each of the eight words in a record could consist of 12 characters, each character being one of the digits of the decimal system (0-9). Therefore, each record would contain 8 times 12 or 96 characters. Since the basic data representative of any data processing system is the binary code, each character would consist of four bits (4 bits will provide 16 possible combinations, only 10 of which are needed to provide representation of the 10 decimal digits.) Therefore, each word would be 4 times 12 or 48 bits. Each record would be 4 times 96 or 384 bits of data. If the master file contained 50,000 records, it would contain 400,000 words, composed of 4,800,000 bits of data. This file would probably be stored on about 2,000 feet of magnetic tape—about one reel.

In summary, the data are organized into a series of levels for processing. These levels are (1) bits, or one-zero representation; (2) character - groups of bits, representing one of the unique symbols of the system; (3) word - group of characters, forming the basic transfer and manipulation unit of the system; (4) record - groups of words, all representing data about the same specific subject; and (5) file - groups of records all representing data about the same general subject. The meaning of these terms and how they are used to control operations within the data processing system is one of the major considerations of this text.

COMPUTERS

The computer is the heart of the data processing system. A computer is a device which will perform sequences of reasonable operations with data, mainly arithmetical and logical operations. A representative electronic digital computer presently in use by some naval activities is the Control Data 1604-A Computer (fig 1-3).

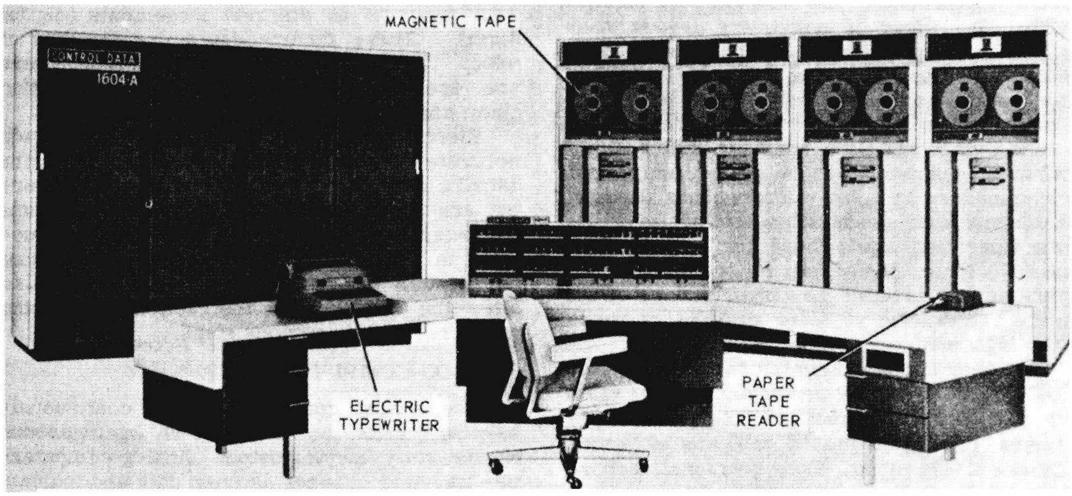

Figure 1-3. —Representative Digital Computer (Control Data 1604-A Computer).

HISTORY OF COMPUTERS

In order to appreciate the high speed and accuracy of computers today, it is desirable to have some knowledge of earlier computers and their originators. The first calculator was built by Pascal in 1642. This machine could add and subtract, and was successfully applied to tax collection in France. In 1671, Leibniz built a machine which could add, subtract, multiply, and divide. Leibniz also recognized the advantages of the binary (or two digit) number system over the decimal (or 10 digit) number system which will be pointed out in chapter 2 of this course.

In 1842, Babbage started a machine called a "Difference Engine." This machine would have been able to construct tables of any function that could be described by the first five differences. Work on this machine ceased, however, when Babbage conceived the idea of an "Analytic Engine" which could tabulate any function. In 1910, his son completed building the latter machine and used it to calculate π to 20 decimal places. Babbage also suggested the use of punched cards (now used as input and output media for computers) and the possibility of a machine that could alter its operations according to the results of its calculations. Present electronic computers resemble his analytic engine in many respects.

Between 1937 and 1944, Aiken built the first general purpose automatic digital computer, called the "Mark I." It is electromechanical, using relays as one of the major calculating devices.

Between 1939 and 1945, Eckert and Mauchly built the "Eniac," also a digital computer. It consisted of 18,000 electron tubes, weighed 30 tons, and dissipated 150 kilowatts. The time required for an add operation was only 0.21 μsec compared to 300 μsec for the Mark I.

In 1951 Eckert and Mauchly built the first "Univac" for the United States Census Bureau.

The "Edvac," completed in 1952, was the first computer to use internally stored instructions (program).

CAPABILITIES

The two major characteristics of computers which make them so useful in military and commercial applications are SPEED and ACCURACY. The speed of computers is seen when we consider that problems which require days, weeks, or years to solve by man, with his slow pencil and paper tools, can be solved in seconds or minutes by a computer. This is conceivable when we consider that a single arithmetic operation can be solved and stored by a computer in a few microseconds whereas a mathematician needs a few seconds to do the same operation and record (or store) it on paper. Thus, the computer can solve the problems and produce an output record of its results, thousands or even millions of times faster than man.

The second characteristic of the computer is ACCURACY. Once a computer is provided with the correct instructions, the planned operations can be repeated millions of times without a single error. Computers make errors only when there is a breakdown in the computing system, or when there is human error in the prepared instructions. Once the breakdown or error is detected and corrected, the computer again operates at high speeds and without error.

Computers are used in many fields of research. In engineering, they are used in design. In business, they are used in bookkeeping and inventory; in government for the census; and by the military, in logistics and battle strategy problems. Any problem which can be reduced to and solved by a sequence of arithmetic steps can be done rapidly by a computer.

DIGITAL COMPUTERS

Computers are classified into two general types; digital and analog, although a variation of these types called a "hybrid computer" has both digital and analog characteristics. The hybrid computer is not treated in this text.

The digital computer, as implied in the name, produces its output by responding to changes in fixed increments, such as 0 to 1, or 1 to 2. The digital change may be accomplished in a gear train; by changing a voltage from one level to another; by the "on" or "off" condition of a switch; by the energized or deenergized condition of a relay; or by the presence or absence of electrical pulses.

Examples of digital devices are adding machines, cash registers, the abacus, thought processes in human calculations, and the odometer used in conjunction with an automobile speedometer.

In this text we shall concern ourselves with electronic digital computers. Here too, the input data must be in discreet increments (digital form). Three factors determine the rate at which the output data is available. These are: memory access time; instruction execution time; and the complexity of the problem.

Electronic digital computers can be made accurate to any desirable degree. They are usually more expensive than analog computers but are also usually more versatile. A digital computer can be given a sequence of instructions in which it can execute later steps using the results of the earlier steps. It can also alter the sequence of instructions according to the results of previous steps.

ANALOG COMPUTERS

The analog computer accepts continuously varying inputs, and supplies an instantaneous continuously varying output. Analog computers use physical changes as input data and indicate the significance which such changes have on the device or unit as a whole. The input/output data may be either electrical, mechanical, or a combination of both. Conditions such as temperature, pressure, and angular position, must be represented by electromechanical analogies. From this, note that an analog computer is, by nature, limited in its application to problems related to specific devices.

The accuracy of the analog computer is limited by the precision of its components, i.e., potentiometers, resistors, etc. Thus, accuracies greater than approximately .001% are not economically feasible.

BASIC COMPUTER BLOCK DIAGRAM

The basic sections of a digital computer are shown in figure 1-4. The three center blocks (arithmetic and logic, internal data storage, and control units) comprise what is generally referred to as the "central data processor."

Control Unit

The control section is comparable to a telephone exchange. It directs the operations of the computer under the direct influence of

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