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CAPABILITIES OF COMPUTERS WITH POSSIBLE APPLICATION IN ELECTRONIC COMMAND SYSTEMS

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CAPABILITIES OF COMPUTERS WITH POSSIBLE APPLICATION IN ELECTRONIC COMMAND SYSTEMS

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March 21, 1949

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PREFACE

Recent developments in the field of electronic computers indicate the possibility of considerably improving the performance of electronic command systems. Accordingly, it is necessary to study the principles of operation in order to give proper consideration to their effect when determining communication and data transmission system specifications.

This report is intended to provide a source of reference information for those who are currently engaged in research and development work on systems for which computer techniques might be applicable. As such, this report first presents a brief outline of the fundamentals of both analogue and digital computer operation. This is followed by a comparison of digital and analogue computers on the basis of field of application, accuracy, limitations, and physical configuration. Examples are offered to illustrate the military possibilities of present day computers to process and route information in transmission systems in response to pre-inserted instructions. The intent of the discussion of these "guided thinking" processes is not to make recommendations, but rather to point out some of the difficulties as well as some of the desirable features of such a system. Some information on present day digital computer projects is given on a chart and the reference list can be employed to gather additional information on specific projects.

PROBLEM STATUS

This is an interim report; work is continuing on the problem.

AUTHORIZATION

NRL Problem R07-25R

CAPABILITIES OF COMPUTERS WITH POSSIBLE APPLICATION IN ELECTRONIC COMMAND SYSTEMS

INTRODUCTION

Present-day naval equipment such as fire-control instruments, radar, and navigation instruments are designed to assist those in command in making decisions regarding identification of friend or foe, in evaluating tactical information, and in carrying out the competent direction of the ship's combat facilities. At the present time the "human element" presents one of the barriers to more efficient operation of the combat command. Inaccuracies may appear in transmission of information by radio and telephone, data may be insufficient for correct evaluation of threat to the ship or fleet, and decisions may be based on errors in judgment. The advent of high-speed planes and missiles obviously calls for the elimination of such errors if the ship is to be of service, both offensively and defensively. This implies mechanization of many of the manual tasks and "guide thinking" processes involved in tactical operations and as a consequence, there would be achieved a rapid and more accurate execution of these operations.

At the present time the designers of equipment incorporate computers to perform many of the functions connected with determination of range and bearing, calculation of complex firing problems, and solutions to problems of navigation. It is reasonable to assume these computers will play an even larger part in future equipment if the suggested mechanization is to be achieved. The digital computers, in particular, have been demonstrated to be quite well adapted for the guided thinking problems. They can be instructed to make choices or render solutions contingent upon prescribed boundary conditions which have previously been inserted in the machine.

This report is intended to serve as an aid to those wishing to familiarize themselves with the progress that has been made in the computer field up to the present time. As has been shown previously, the computers are roughly divided into two groups. The first group includes all the various analogue machines, these being characterized by continuous solutions. The second group comprises the digital machines, which calculate from discrete increments of the variables and render discrete answers. A section is included which compares the relative merits of the two types from the standpoint of accuracy, flexibility, and applications. The comments on military applications are not intended to prescribe boundaries for future development, but merely to discuss in general some of the problems involved. An example is included which illustrates some of the aspects of the problem. The presentation of data is necessarily somewhat limited, and if more detailed information on a particular project is desired, the reference list will aid in locating pertinent reports. A chart showing the characteristics of digital computer projects and also data on those already in operation is attached to this summary as a ready means of reference.

ANALOGUE COMPUTERS[1]

An analogue computer consists of a group of elements which will perform in exactly the same manner as some other system which it is designed to represent. Information is first obtained from operation of the analogue and then referred to the original system, thus making this computer a powerful agent for the solution of complex physical or mathematical problems. Individual computers vary widely in appearance and operation, but the components may be grouped roughly into three basic units as shown in the accompanying figure. They are the simulation or mathematical unit which actually performs the operations, the function and constant input unit for inserting information (such as the constants in a differential equation), and the output indicators for recording solutions.

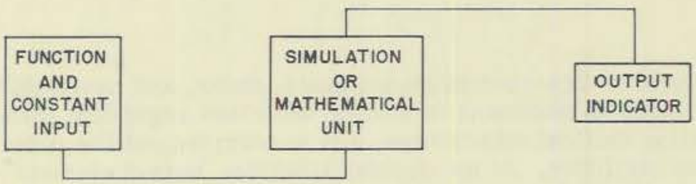

Fig. 1 - Table of Computers

Physical Analogue Computers

The physical analogue computers represent one of the two general types of analogue computers (operational analogue computers are the other type). In this type, emphasis is placed upon a one-to-one correspondence between the parameters of the original system and its mechanical or electrical analogue. The equivalent electric circuit is the most widely used of this type and is particularly useful in simulating linear systems, and many instruments, notably network analyzers, operate on this principle. The large network analyzers fall into three categories: transient analyzers, AC analyzers, and DC analyzers. (The last two may be grouped together under the heading of steady state analyzers.)

Large transient analyzers are located at the Westinghouse Manufacturing Company, East Pittsburgh, Pennsylvania; at the California Institute of Technology, Pasadena, California; and at the General Electric Company, Schenectady, New York. Machines of substantial size are being constructed by Mr. George Philbrick of Boston, by the Research Laboratory of Electronics at the Massachusetts Institute of Technology, and by others.

Large AC analyzers are owned by the General Electric Company and the Westinghouse Electric Corporation, and by various universities, notably the Iowa State College, Ames, Iowa.

Large DC analyzers are in use at Columbia University (Dr. V. Pashkis) and at the Resonant Cavity Project at Stanford University, as well as at General Electric, Westinghouse, and many other companies.

Operational Analogue Computers

Most of the larger and more expensive of the analogue machines fall into the operational class. They are so called because interest is focused on the basic operations involved in a set of equations. Typical operations are addition, subtraction, multiplication, division, integration, differentiation, etc. Thus, if a collection of devices is available, each of which

[1] Quoted in part from a talk given by Dr. H. M. Trent at the Symposium on Computers held at the Naval Research Laboratory, August 25, 26, and 27, 1948.

will simulate a mathematical operation, and a method is provided for rapidly connecting these together, then a solution from a complex set of equations can be obtained quickly. A standard, automatic, large-scale operational machine for solving ordinary differential equations is the Bush mechanical (or electromechanical) differential analyzer, the most advance model being installed at the Center of Analysis, Massachusetts Institute of Technology (where there is also an older mechanical differential analyzer). Four similar machines in this country are located at the General Electric Company, Schenectady, New York, the Moore School of Electrical Engineering, Philadelphia, Pennsylvania, the Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, and the University of California at Los Angeles, California.

Several electronic versions of large-scale mechanical differential analyzers are in the process of being built. These are classified projects and are known by code names. Two somewhat similar programs are Project "Cyclone," a Navy contract with the Reeves Instrument Corporation of New York, and Project "Typhoon," a Navy contract with the Radio Corporation of America and under development at RCA Laboratories, Princeton, New Jersey. In part, both projects call for the development of a rapid, precise, and automatic computer which will simulate in detail the flight of a guided missile and thus permit study and evaluation of the performance of existing and proposed guided missiles. A slightly improved version of the "Cyclone" machine is being constructed by the Reeves Instrument Corporation for the Naval Research Laboratory at Washington, D. C. The Dynamic Analysis and Control Laboratory at the Massachusetts Institute of Technology has a Navy contract ("Meteor") for the development of a homing missile suitable for defense against aircraft which travel at speeds up to 600 miles per hour and at altitudes up to 60,000 feet. The associated equipment is to include a guided missile simulator embodying an electronic analogue computer of advanced design. Bell Telephone Laboratories has a similar Army project called "Nike" which also employs an advanced electronic analogue machine.

Machines for solving differential equations are generally by far the more complex and expensive analogue machines, those for other purposes tend to be much simpler and less expensive. Of those concerned with the problem of solving algebraic equations, the most widely used are the machines which solve simultaneous linear equations. The Consolidated Engineering Company, Pasadena, California, has developed one such unit and the International Business Machine Corporation another. Numerous machines have been developed for finding the roots of polynomial equations, and, in addition, nearly all types of fire-control equipment and training devices incorporate analogue computers. They give solutions to problems which range from the triangulation work connected with anti-submarine attacks to the ranges and bearings calculated for gunfire control.

DIGITAL COMPUTERS[2]

The "digital" as contrasted to the "analogue" computer utilizes discrete increments in mathematical processes. Where the analogue machine provides a continuous answer and plots smooth curves, the digital computer performs a numerical computation and produces a numerical answer. In digital machines, combinations of pulses are used to represent numbers and control orders. However, the very great speed of the digital machine enables it to calculate incremental points on a curve in a time comparable with that of the analogue machine. There are three major internal units which make up most digital computers: The arithmetic, the control, and the internal memory units. A sketch of the general layout follows.

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[2] Quoted in part from ONR Restr. Report B-1741, "A Survey of Large Scale Computers and Computer Projects," Office of Naval Research, Navy Dept., August 1948.

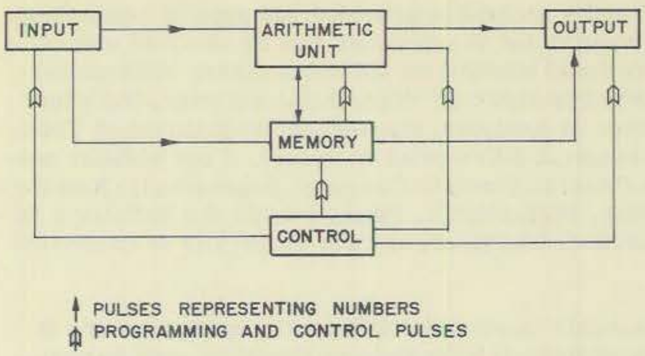


Fig. 2 - Status of Digital Computer Projects

The Arithmetic Unit

This unit performs all the functions associated with computation. Combinations of pulses which represent numbers are received from the input or memory as the case may be, the mathematical operation is performed, and the result is returned to the memory or to the output of the computer. Some machines have a complex arithmetic unit which will perform a variety of operations such as roots, reciprocals, differentiation, and integration, as well as the simpler arithmetic operations. Such a unit is necessarily very complicated and difficult to construct. An alternative is to reduce the arithmetic unit to an adder and to program all other operations so that the proper operation will be performed by this unit. Formulas have been developed for the processes other than addition whereby repeated additive operations (iteration) will yield the desired result. Ordinarily the construction of the arithmetic unit is somewhere between these two extremes depending on the specifications of the computer design.

The Control Unit

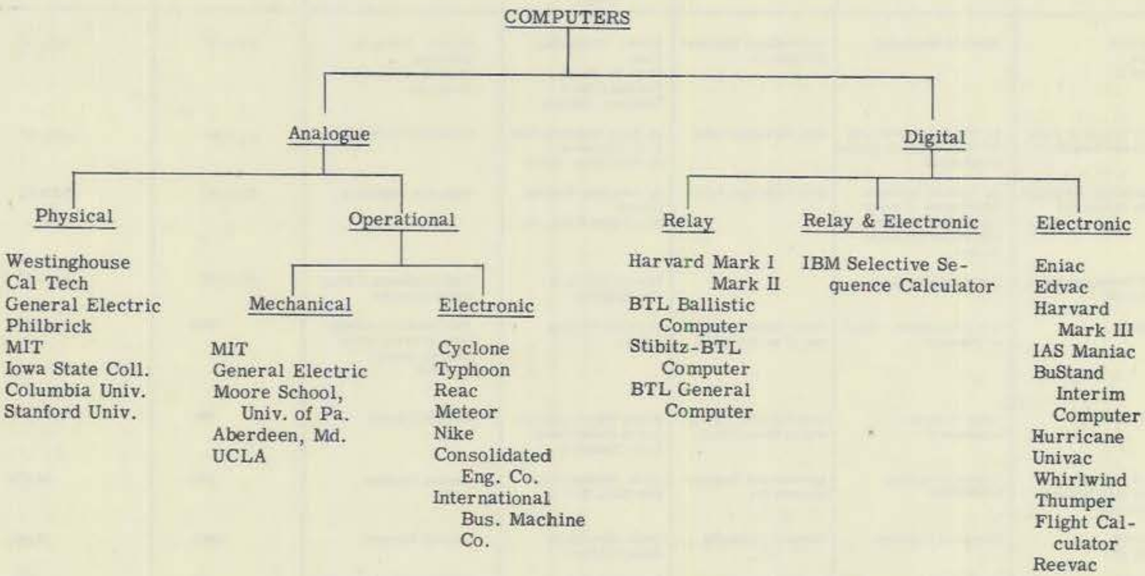
There are two separate methods for handling control orders. One is to hold all orders externally so that the machine will return to the control input for a new order after each operation. Slow-speed computers employ this system to advantage as it aids in error location and control. Higher speed machines store coded orders in the internal memory in the same manner in which numbers are stored and thus increase the speed with which orders become available. A compromise is sometimes worked out whereby orders which are needed quickly are stored internally and the external input is called on intermittently for order information. In addition to direct orders to perform arithmetic operations, transferrence of information within the machine and many other operations may be directed through the order control.

The Internal Memory

In general, there are two classes of memory media. The first group stores pulses in a set of space dimensions, and the second group stores pulses in the time dimension. The first class includes printing on magnetic or paper tape or the storage of pulses electrostatically. The second class includes the delay type of memory such as the electric delay line or the mercury acoustic delay line. Access time when referred to computer memories means the time necessary to enter the memory, locate a number, and place it in some other unit. A small access time is highly desirable in a memory as well as large capacity or storage. It has been estimated that a machine which would handle large problems such as partial differential equations or problems in statistics would require a memory capacity of 10,000 to 1,000,000 words where a word contains the same number of digits as the maximum number of significant figures of which the machine is capable. Although many types of memory storage are in use in operating machines, the choice of a storage system for those computers now under construction is centered on two types: Mercury acoustic and the electrostatic storage devices. The latter system promises to be far superior because the access time will be much less than for the mercury acoustic system. However, at present, certain design problems have been encountered in development, and research on these devices is being continued.

Because of their tremendous cost and complexity, a rather limited number of digital computers have been built. Many civilian and government agencies have indicated a desire for the services which these instruments have to offer. Table 1 shows the general classification into which each machine falls. Table 2 lists characteristics of digital machines, both completed and under development.

TABLE 1
Classification of Computers



COMPARISON OF ANALOGUE AND DIGITAL MACHINES

The physical analogue computers are used largely in the field of electromechanical analogies, and it is here that they will probably continue to be popular inasmuch as digital computers are inapplicable. They are characterized by low cost, availability, ease of assembly, ease of variation of parameters, and ease of observation. Of primary significance is their importance as tools in the advancement of knowledge of physical systems.

The operational analogue computers are ordinarily rather inflexible but find application in situations calling for solutions to a restricted set of equations. Under such conditions, they may in one operation produce the solution of some computation which is tremendously complicated when compared to the unit operation of digital machines. The continuous accuracy depends on the structure and precision of the parts which represent the numbers. As an example, the error of an uncompensated bar linkage multiplier is approximately 0.3 percent with an absolute minimum of 0.1 percent. The error associated with a synchro depends on the size of the unit and the torque required to actuate the associated elements. The absolute minimum, however, is in the neighborhood of 0.1 percent for the larger types. Servo systems which combine these and other elements must be analyzed individually to determine the percentage error which exists, but in any case, the

TABLE 2
Characteristics of Digital Computer Projects

PROJECT	AGENCY SUPPORTING WORK	CONTRACTOR OR LABORATORY	LOCATION OF THE ACTIVITY AND PERSONNEL INVOLVED IN THE WORK	AIMS OF INVESTIGATION OR APPLICATION OF THE INSTRUMENT	ADDITION TIME (μsec.)	MULTIPLICATION TIME (μsec.)
Harvard Mark I Mark II	Harvard University	International Business Machine Co.	Mark I. Cambridge, Mass. Mark II. Naval Proving Ground Dahlgren, Virginia	Mark I. Tables of Functions Mark II. Ordnance Problems	2.0×10^5	7.0×10^5
Bell Telephone Labs Ballistic Computer	(a) Naval Research Lab (b) U. S. Army Ordnance Department	Bell Telephone Labs	(a) Naval Research Lab C. H. Chrisman (b) Fort Bliss, Texas	Ballistics Problems	2.4×10^5	2.6×10^5
Stibitz Bell Telephone Labs Computers	(a) Chief of Ordnance Department of Army (b) National Advisory Committee for Aeronautics	Bell Telephone Labs	(a) Aberdeen Proving Ground (b) Langley Field, Va.	Ordnance Problems	2.0×10^5	2.0×10^5
Bell Telephone Labs Computer	Bell Telephone Labs		Murray Hill, N. J. Mr. McMillen	Digital solution of electrical networks	2.0×10^5	2.0×10^5
ENIAC	War Department - Chief of Ordnance	Moore School, University of Pennsylvania	Aberdeen Proving Ground	Most useful in calculations of firing tables (limited general purpose)	2000	2800
EDVAC	Army Ordnance Laboratory	Moore School, University of Pennsylvania	Moore School, University of Pennsylvania Prof. Chambers	General Purpose	650	2600
I.B.M. Selective Sequence Electronic Calculator	Watson Computing Laboratory	International Business Machine Co.	I.B.M. Headquarters, New York, N. Y.	General Purpose	300	20,000
Harvard Mark III	Bureau of Ordnance	Harvard University	Cambridge, Mass. Howard Aiken	General Purpose	4000	12,500
I.A.S. Computer Maniac	U. S. Army Ordnance Department	Institute for Advanced Study	Princeton, N. J. Prof. J. von Neumann	Development of very high speed, general purpose machine. Selectron memory	80	160
Bureau of Standards Interim Computer	Air Force	Bureau of Standards	Bureau of Standards Lab, Harry Husky	Small general purpose for Institute for Numerical Analysis at U.C.L.A.	650	2600
Raytheon Digital Computer Hurricane	Office of Naval Research-Contract N7-ONR-38902 RDB-NR 723 001 SDC24X4	Raytheon Manufacturing Co.	Waltham, Mass.	General problems in mathematical analysis for National Bureau of Standards	730	900
Census Computer UNIVAC	National Bureau of Standards	Electronic Control Co.	Philadelphia, Pa.	Bureau of Census statistical computation	500	1300
Whirlwind	Special Devices Center ONR - Contract N5-ori-60 RDB - NR 720 003 SDC 24X3	Mass. Institute of Technology	Cambridge, Mass. J. W. Forrester	Development of device to simulate airplanes in flight. Includes a high speed digital computer	30	40
Thumper	U. S. Air Force Air Materiel Command	General Electric Co.	Schenectady, N. Y. G. W. Hobbs A. D. Dodge	Control of guided missiles	25	35
Flight Calculator	Watson Lab Air Materiel Command Eng. Order 178-17 Contract W28-099 ac244	Teleregister Co.	New York, N. Y.	Computation of flight path for missiles	650	2600
REEVAC	University of Illinois	Reeves Instrument Corp.	New York, N. Y.	To be located at the University of Illinois. Theoretical investigations	650	2600

TABLE 2 (Cont.)

INTERNAL MEMORY TYPE	INTERNAL MEMORY CAPACITY	EXTERNAL MEMORY	INFORMATION INPUT MECHANISM	SOLUTION OUTPUT MECHANISM	MATHEMATICAL SYSTEM	DEGREE OF COMPLETION	REFERENCES
Relay	100 ten decimal digit numbers	Paper tape	I.B.M. cards or paper tape	I.B.M. cards or paper tape	Decimal	In operation	References 1, 2
Relay	10 five decimal digit numbers	Teletype tape	Teletype tape	Teletype tape	Bi-quinary	In operation	Reference 21
Mechanical Counters	72 twenty-three decimal digit numbers	I.B.M. cards or paper tape	Paper tape	Paper tape	Decimal	In operation	References 1, 2, 46
Relay	12 ten-decimal digit numbers	Teletype tape	Teletype tape	Teletype tape	Bi-quinary	Design completed	References 21, 46
Electronic Counters (flip-flops)	20 ten-decimal digit numbers	I.B.M. cards	I.B.M. cards	I.B.M. cards	Bi-quinary	In operation	References 1, 2, 6,7, 10, 15, 43
Acoustic delay lines	1024 forty-four binary-digit numbers	Magnetic wire	Magnetic wire	Magnetic wire	Binary	In process of test	References 1, 2, 4, 22
Relay and Electronic Counters (flip-flops)	160 twenty binary-digit numbers	I.B.M. cards	I.B.M. cards	I.B.M. cards and printed record	Binary	In operation	References 1, 2, 4
Magnetic drum	4000 sixteen-decimal-digit numbers	Paper or magnetic tape	Magnetic tape	Magnetic tape	Coded decimal	Completed October 1949 (est.)	References 1, 2, 12, 22
Electrostatic Storage Tubes	4096 forty binary-digit numbers	Magnetic wire	Paper tape	Paper tape	Binary	Design ½ completed	Reference 1
Electric delay lines	1000 twenty binary-digit numbers	Paper tape	Teletype tape	Teletype tape	Binary	June 1949 (est.)	References 1, 2, 21
Acoustic delay lines	1024 thirty-five binary-digit numbers	Magnetic tape	Magnetic tape	Magnetic tape	Binary	Final design stage. Project completion date 1 June 1950 (est.)	References 1, 2, 22
Acoustic delay lines	1000 forty-eight binary-digit numbers	Magnetic tape	Magnetic tape	Magnetic tape	Coded decimal	Final design stage	References 1, 2, 47
Electrostatic Storage Tubes	32,000 forty to fifty binary-digit numbers	Magnetic wire and film	Magnetic wire and film	Control orders and magnetic wire	Binary	Prototype tested by July 1949 (est.)	References 2, 39
Electrostatic Storage Tubes	15 thirty to thirty-five binary-digit numbers	Magnetic drum	Equipment for utilizing radar data	Control orders	Binary	Design stage	Reference 36
Acoustic delay lines	1525 twenty binary-digit numbers	Magnetic tape and drum	Equipment for utilizing radar data	Control orders and magnetic wire	Binary	Study completed	Reference 48
Acoustic delay lines	1024 forty-four binary-digit numbers	Magnetic wire	Magnetic wire	Magnetic wire	Binary	Design stage	References 1, 2, 22

accumulation of small errors cannot be avoided. The overall error for an operational analogue, then, is limited by human capacity in constructing flawless devices and by the effects of temperature changes, air pressure changes, humidity variations, and the age of such devices. An overall error of 1 percent might be taken as fairly representative of the degree to which they are being designed today.

Digital machines, although employing fundamental processes, are controlled through each and every step of an involved operation by the programming unit. Orders are issued from this unit directing that specific operations be performed throughout the machine. The operations are usually elementary in character — addition, subtraction, multiplication, division, etc. New developments in machine mathematics enable integrals, differentials, roots, reciprocals, etc., to be evaluated by methods of arithmetic. Problems of coding operations have been simplified and code libraries are an aid. As an example, when orders for a particular problem in a class are completed, it is then not too difficult to modify the directions so as to apply to other types of problems in that class as well. Thus, the computer is a highly flexible calculating instrument and only the restrictions of coding limit the applications. Digital computer accuracy depends on the magnitude of two errors. They are truncation errors and round-off errors. The first occurs in mathematical operations where a number of terms in a series are discarded or perhaps where an iterative operation is discontinued before the desired accuracy is reached. Round-off errors occur in the arithmetic processes in a computer when digits must be dropped since storage registers will accommodate only a given number of significant figures. Errors in both analogue and digital machines may be reduced, but the relative cost in terms of the additional equipment required is much less for a digital machine.

MILITARY USEFULNESS OF COMPUTERS

The choice of a digital or an analogue computer for a military application is based on the consideration of a number of design factors. They are accuracy, size, weight, reliability, speed of computation, range of application, etc. Many problems do not require the extreme speed and accuracy that can be obtained from digital machines, and it is expected that in those cases the analogue computers will continue to be used. In addition, space and weight limitations in many cases favor analogue computers. Digital machines, on the other hand, can provide the necessarily rapid solution to extremely involved problems such as missile flight control. Several units are being designed expressly for this purpose on military contracts (e.g., Thumper, Hurricane) and since they are designed for specific functions, they tend to be far smaller than the mammoth general purpose ones such as the ENIAC (18,000 tube envelopes) and the EDVAC (3,000 tube envelopes). Other general purpose machines both under construction and in operation are not immediately applicable, but computers embodying similar techniques could be made available for use as military command-center equipment. The digital machines which depend on relay operation have severe speed limitations when compared to electronic instruments, and thus would be suitable only in a restricted military field. It must be emphasized, however, that the relay machines are more reliable in operation than electronic machines when comparisons are made on a research problem.

An important problem in the application of electronic computers, from the military point of view, is the development of input, output, and control devices. In order to appreciate the complexity of this situation, the solution of a scientific problem by an all-purpose electronic computer may be considered. Assume that an engineer encounters a situation in his work wherein specific information can be obtained most effectively by appropriate but time-consuming computation. His first step is to describe the physical relationships of the situation mathematically - i.e., setting up equations in terms of the unknown quantities representing the variables of the desired information. In the case of differential equations, boundary conditions would have to be known. The engineer presents the equations to the computing mathematician, who in turn might have to reduce the equations to a form which will be most adaptable to computation. Next the problem must be programmed into the computer - i.e., it must be coded for reception and interpretation by the computer. The coded information includes not only the variables and parameters of the problems but also the instructions for the mathematical operations to be performed in the proper sequence according to the equations. The computer then solves the problem, and the solution from the output must be decoded.

For military applications, automatic devices are necessary to perform the above manual operations between the realization of the specific problem and its insertion into suitable computing components. Since the number of problems for which solutions required are limited, the coding process can be previously inserted and thus eliminate loss of critical time in obtaining solutions. The system cannot be completely fixed however, and manual adjustments should be provided to cope with variations in the nature of the attack or defense problem. As an example of this situation, consider a theoretical fighter-intercept control system geared to cope with enemy targets flying at 1000 miles per hour. Assume that radar information provides the instantaneous flight path of both the target and a specific interceptor (probably a missile). Now practically instantaneous instructions from the control ship are necessary for interception in the minimum possible time. The intercept system might function as follows: The radar information is recoded to fit the coding system of the computing elements. The computing instructions (sequence of operations) are entirely built-in or automatic and can be modified by the machine to furnish the most appropriate solution consistent with the input data. The computing mechanism controls are not actually "thinking" - they are simply making a definite choice in accordance with current circumstances described precisely by the input information. After the necessary computations are performed, the control orders are transmitted to the missile to permit interception in a minimum time.

CONCLUSIONS

At the present time the techniques of digital computer construction have progressed to a point where quite dependable operation can be expected. However, input, output, and communication equipment which will permit the use of these computers in military applications is not too far advanced. Several projects (e.g., Whirlwind, Thumper) are studies toward the design of digital computer control systems and have made some progress in this respect.

The development of analogue computers is being aided by the introduction of electronic techniques for greater accuracy and more simplified construction. Project "Cyclone" is an example of present design trends. The wide variety of situations for which such equipment must be provided render it impracticable to be more specific as to military usefulness. It is felt however, that the incorporation of digital and electronic analogue computer elements into tactical equipment will aid in the mechanization of that equipment.

EXPLANATION OF TABLE 2 (See pp. 6 and 7)

The computers represented in Table 2 cover those under development, as well as those already in operation. In the case of the latter, the information is accurate. For those under construction, the information can be depended upon only to give an indication of the manner in which the machine will operate. Such factors as changes in design and the outcome of component development will greatly influence the final operational characteristics.

The computer project names are those which have been used previously in reports and are used here for identification purposes. The more important of the column headings will be explained in the following paragraphs.

Column 4 - Location of the Activity and Personnel Involved in the Work. For the computers which are in operation, the address of the computer location is given. The address of the factory or laboratory which is doing the work is given for those projects which are not yet completed.

Column 5 - Aims of Investigation or Applications of the Instrument. The construction of a computer would be extremely involved if it were made completely general purpose. Instead, the so-called general purpose machines are those that may solve many, but not all, of the present-day problems in industry and science. It will also be noticed that several instruments (e.g., the NRL computer) are made to solve ordnance problems. Because these computers have been developed for special problems, they are more easily used for their specific applications. However, in many cases and sometimes through modifications, they can be coded to solve some other classes of problems as well. It is understood that at least one of the flight instruments has a dual input. That is, it may also be used as a general purpose computer.

Column 6 and 7 - Addition and Multiplication Time. In general, this column indicates the time necessary to obtain the order and the two numbers from the internal memory, add or multiply as the case may be, and place the result in the internal memory. This elapse of time is not an exact criterion since the machine may operate in serial or parallel. If the arithmetic unit is a serial unit, the digits which make up a word must be added to the corresponding digits of another word in succession, and if it is a parallel unit, all the digits of a word are operated on simultaneously. However, parallel operation greatly increases the amount of equipment and hence the cost. Thus, only in cases where extreme high computing speeds are necessary is parallel operation used.

Column 8 - Internal Memory. The memory in a computing machine is a device which stores numbers and orders so that they may be employed at the proper time in the process of computation. Four general classes of memory are listed: electric delay lines, acoustic delay lines, magnetic drum or tapes, and electrostatic storage tubes. At the present time acoustic delay lines represent perhaps the most economical system in terms of space and equipment but considerable effort is being made to improve the electrostatic storage tube. If this work is successful, a system will be available which will have greatly increased storage capacity and in which any number can be inserted or removed from storage almost instantaneously.

Column 9 - External Memory. The external memory for many of the computer projects uses the same medium for recording as is employed in the input and output system. It is ordinarily used to store information which is not needed except at infrequent intervals, such as tables of functions.

Column 10 and 11 - Information Input and Solution Output Mechanism. The present methods of input and output will fall roughly into two groups — the slow and the fast. The slow method employs paper tape, teletype tape, and I.B.M. Cards. Since teletype tape is five punch holes wide, a faster tape input has been developed by increasing the width of the paper tape and hence the number of information holes across the tape. Even with this improvement, the input mechanism would severely limit the overall computer speed unless a comparably slow arithmetic unit were used or if a fast arithmetic unit were performing iterated operations.

The fast group of input and output devices includes magnetic wire, magnetic tape, film, and devices for radar information. Magnetic tape has more storage capacity than magnetic wire since several channels of information may be impressed on a single tape. Photographic film is somewhat less satisfactory because it requires an increased preparation time and because it can be used only once. All these systems permit the impression or removal of information while the wire, tape, or film runs at very high speeds. In addition, they lend themselves admirably to systems using binary-digit computing techniques.

Column 12 - Mathematical System. The first computers utilized relays throughout all operations including the storage of numbers. For such systems the decimal number system or variations of the decimal number system, such as the bi-quinary system, were used. A bi-quinary machine represents the five digits, 1, 2, 3, 4, and 5, by relays. Then by combinations of these relays any figure from 0 to 9 may be produced. The system thus uses fewer relays than the decimal machine. With the advent of the electronic computers it was found that positive on-off stable-state conditions were desirable in the vacuum tube circuits. As a consequence, the binary pulse system was found to be more satisfactory, and it and the coded decimal method are now generally employed. The coded decimal system utilizes a special arrangement of four binary digits to represent each of the ten decimal digits and control orders.

Column 14 - References. References are made to many of the articles listed in the Bibliography of this report.

FOREIGN COMPUTER PROJECTS

For information on foreign computer projects, refer to ONR Restr. Report No. B-1741, "A Survey of Large Scale Computers and Computer Projects," August 1948.

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The latter portion of this bibliography lists a number of sources which are believed to indicate present trends in many phases of computer theory and design. To these citations are appended short descriptions of their subject matter.

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36. Rogers, D. R., Considerations in the Design of a Digital Computer in the Thumper System (Preliminary Report), 2 July 1948 (Confidential). Project Thumper, General Electric Company Report TR55415.

As outlined, the Thumper computer is to be a digital type machine employing high speed computation. Work on the computer is progressing along two lines: The first, a continuation of laboratory work on the general circuits required for any system of equations, the second, an analysis of the equations which must be solved to determine missile position from the missile range to three ground stations in order to establish the number of mathematical operations involved and the time required for solution. Memory is to be provided by means of electrostatic storage tubes. Selective matrices have been developed at General Electric and are used in the computer. The matrix is a device by which a theoretical limit of 4096 outputs may be controlled by only 12 circuit inputs.

Input to the computer is in the form of readings from radar equipment and outputs are given in terms of course orders to missiles.

37. Attack Director, Mark 4 Mod 1, and Amplifier, Mark 34 Mod 0; BuOrd OP 1646, 16 February 1948 (Restricted).

This analogue computer, a mechanical device performing all mathematical operations by the lever, wheel, and cam method, solves triangulation problems connected with anti-submarine attacks. It receives information in the form of shaft rotations and calculates bearings, ranges, and timing so that an attack may be carried out.

38. Progress Report on Activities in Connection with the Parallax Computer and Radar Modifications, The Franklin Institute Progress Report No. 9, 1 June 1948 (Confidential).

The computer problem in connection with this task has reached the design stage and is shown in block diagram form. It is an analogue type computer which employs servomechanism integrators as well as mechanical devices for other operations and continuously solves the equations of flight for the purpose of controlling drone aircraft.

39. Project Whirlwind, MIT Servomechanisms Lab. Summary Report #6, March 8, 1948 (Confidential).

The Whirlwind program, as outlined, has as its main purpose the simulation of airplanes in flight. The most important task is to develop a digital computer of large storage capacity and very high speed. The report covers various phases in the development of the components of the computer, an example of which is the electrostatic storage tube being developed in cooperation with the Sylvania Electric Products Co. A bibliography is given of more detailed reports covering other phases of the project.

40. Lovell, C. A., "Continuous Electrical Computation," Bell Lab. Record, 25, 114-118, March 1947.

When computers are used in the problems of fire control, it is necessary that continuous data be furnished to the gun mount. To meet that demand, potentiometers are used in this circuit for addition, multiplication, and division. If functions such as sine, cosine, log, etc., are desired as multipliers, the width of the potentiometer card

may be made proportional to that function. Amplifiers are used to provide scale factors. The article discusses all operations in terms of the fire control problem, but this potentiometer technique may be applied in other fields as well.

41. Page, C. H., "Digital Computer Switching Circuits," Electronics, 21, 110-118, September 1948.

A survey is made of the basic operational requirements and the methods used to obtain the desired results. The discussion includes methods of addition and multiplication, information on the method of memory storage by mercury tubes, systems of control, and the merits of the binary number system. It concludes with suggestions for locating errors and insuring accuracy.

42. Rockett, Frank, "The Electron Art - Selective Sequence Digital Computers," Electronics, 21, 138-140, April 1948.

The computer described in this article is the latest model made by the International Business Machines Corp. and was designed under the direction of F. E. Hamilton. Information is given as to the ability of the instrument, its capacity, and a general outline of its constructional features. It concludes with an enumeration of some of the special design problems.

43. Burks, Arthur W., "Electronic Computing Circuits of the ENIAC," Proc. IRE, 35, 756-767, August 1947.

The ENIAC (Electronic Numerical Integrator and Computer) is a very large unit but is compounded of a few basic types of computing circuits. The design principles are presented and the basic computing circuits are analyzed. The ENIAC performs the operation of addition, subtraction, multiplication, division, square root, and the tabling of functions. The technique of combining the basic electronic circuits to perform these functions is illustrated by three typical computing circuits; the addition circuit, a programming circuit, and the multiplication circuit.

44. Frost, Seymour, "A Compact Analogue Computer," Electronics, 21, 116-122, July 1948.

This computer obtains solutions to problems which may be stated in equation form. It is particularly useful in the solution of differential equations and will handle such equations of the seventh order. The article outlines the principal elements of the computer, gives an illustration of its operation, and describes exactly the part performed by each of the various units.

45. Sharpless, T. K.,"Design of Mercury Delay Lines," Electronics 20, 134-138, November 1947.

The Moore School at the University of Pnnnsylvania has designed the EDVAC computer. In this connection they have initiated the developmental work on mercury delay lines as a means of storage. Information is given on the design requirements and the operating characteristics of these lines, as well as some of the associated circuits in which they are used.

46. Williams, S. B., "A Relay Computer for General Application," Bell Lab. Record, 25, 49-54, February 1947.

The Bell Laboratory instruments use perforated tapes to feed in information and the manner in which they are produced and used is explained. The article is restricted to control and use of the machine and no mathematical circuits are discussed. A method for checking errors on tapes is also described.

47. "Summary Report on the Univac," Eckert-Mauchly Computer Corp. (Electronic Control Company), November 1947 (Unclassified).

A very detailed description is given here of the operation of the Univac machine. Emphasis is placed on the coding system which was finally chosen after a great many earlier revisions in the construction of the machine. This coding system is discussed here in detail. The report concludes with an extensive discussion of the merits of small components, particularly tubes and germanium diodes. Information on the component circuitry is omitted, however, as is an explanation of some of the minor elements.

48. May, H., "The Flight Calculator," The Teleregister Laboratories, Engineering Report #10, October 1947 (Secret).

This progress report covers the preliminary planning toward the development of a digital computer for the purpose of calculating the flight paths of missiles. The computer, as envisioned, employs very high speed calculating elements, and reasonably high speed input and output. It is conventional, however, in the layout and operation, with the exception that it will solve only a given set of equations.

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