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AUTOMATIC HIGH SPEED COMPUTING

A Progress Report on the EDVAC Sep 30 1945

by Eckert x Mauchly

Part 1 INTRODUCTION AND SUMMARY

1. Historical remarks
2. observations about sorting
3. von Neumann's early draft of order code

1.0 HISTORICAL COMMENTS

The Ballistic Research Laboratory of the Aberdeen Proving Ground is forced, by the nature of its work, to carry out numerical computations which are notable both for their volume and for the variety and complexity of the procedures employed. Of necessity, the Laboratory has become an important computing center. To expedite its work, it has sought improved techniques for the use of existing equipment and has fostered the development of new devices for "mechanizing" and speeding up the processes of numerical computation.

[with modification, p77]

In August, 1942, J. W. Mauchly summarized briefly, in memorandum form, the advantages to be expected from an electronic high-speed computer such as could reasonably be developed at the time. Capt. Herman H. Goldstine, of the Ballistic Research Laboratory, and Col. Paul N. Gillon, of the Office of the Chief of Ordnance, became interested in the possibilities of such a device for the Laboratory. Mauchly and J. P. Eckert, Jr. then wrote out a tentative technical outline of a machine which would be capable of numerically integrating trajectories for firing tables and which would handle other computing jobs of similar complexity. J. G. Brainerd then incorporated this material into a report which was submitted to the Ballistic Research Laboratory. The United States Government then entered into a contract with the University of Pennsylvania, to have the Moore School of Electrical Engineering carry out research and development on electronic calculating devices for the Ballistic Research Laboratory. The project was set up under the administrative supervision of Dr. Brainerd with Mr. Eckert as chief engineer and Dr. Mauchly as principle consultant; Captain Goldstine was appointed to take technical cognizance of the project for the Laboratory.

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Under this contract, a staff at the Moore School have, since July 1, 1943, worked continuously on the design and construction of electronic computing devices. A first machine, the Electronic Numerical Integrator and Computer (ENIAC) has been designed and constructed, and will soon be put into operation. It was necessary, in order to complete a task of this magnitude in little more than two years, to fix the design at an early date and to concentrate thereafter on production and testing.

During this latter period of work on the ENIAC, it became more and more evident that close scrutiny should be given to the way in which the high speed of electronic devices could be utilized in computing machines. It became apparent that serial operation was in general advantageous, and that when serial methods were used wherever possible the equipment was used most efficiently. Hence, in January, 1944, a "magnetic calculating machine" was disclosed, wherein the successive digits of a number were transmitted in timed sequence from magnetic storage or memory devices through electronic switches to a central electronic computing circuit and similarly returned to magnetic storage. An important feature of this device was that operating instructions and function tables would be stored in exactly the same sort of memory device as that used for numbers. The electronic switching means for such a machine were already disclosed -- the ENIAC function tables use one form of such a switch.

The invention of the acoustic delay line memory device by Eckert and Mauchly early in 1944 provided a way of obtaining large high-speed storage capacity with comparatively little equipment. An automatic electronic calculating machine was then planned, using the delay line device for the "internal" memory, and using the somewhat lower speed magnetic devices only for input and output mechanisms.

It was clear that this new machine would, with much less equipment, easily handle problems beyond the intended scope of the ENIAC. Therefore, by July, 1944 it was agreed that when work on the ENIAC permitted, the development and construction of such a machine should be undertaken. This machine has come to be known as the EDVAC (Electronic Discrete Variable Computer).

Although pressure of work on the ENIAC has made it impossible to conduct much experimental work on the EDVAC, all of the essential components to be used in the EDVAC are known to work. In designing a specific machine, however, a great number of decisions must be made -- decisions as to quantity and proportion of various parts, and decisions as to which of several possible methods shall be employed. During the past year, many questions of this sort have been considered in a series of discussions held just for this purpose.

During the latter part of 1944, and continuing to the present time, Dr. John von Neumann, consultant to the Ballistic Research Laboratory, has fortunately been available for consultation. He has contributed to many discussions on the logical controls of the EDVAC, has proposed certain instruction codes, and has tested these proposed systems by writing out the coded instructions for specific problems. Dr. von Neumann has also written a preliminary report* in which most of the results of earlier discussions are summarized. In his report, the physical structures and devices proposed by Eckert and Mauchly are replaced by idealized elements to avoid raising engineering problems which might distract attention from the logical considerations under discussion.

*First Draft of a Report on the EDVAC: June 30, 1945

It must be emphasized that final decisions on many questions cannot yet be made. In many cases, closer study of alternative circuit designs of further experimental data will be necessary before intelligent choices can be made. The discussions that have been held have served an essential purpose by formulating the important questions and indicating what experimental data is pertinent to their answers.

1.1 CONTRAST OF THE EDVAC WITH THE ENIAC

The EDVAC and the ENIAC have very little in common. Although they are both electronic digital computing machines, the resemblance ends there. A few salient contrasts will emphasize this. In many respects the ENIAC is an electrical analogue of mechanical computing machines: it has decade counters instead of decade gear wheels, and all the decimal digits of a given number are added simultaneously as in any mechanical adding machine. Multiple channels and multiple equipment are necessary to do this. In the EDVAC, the various digits specifying a number will be transmitted serially through a single channel. Switching equipment is consequently simplified and reduced. Moreover, the storage or memory elements to be used in the EDVAC are entirely different from those used in the ENIAC. A typical unit, involving about 10 vacuum tubes, can be made to hold many digit sequences in definite time relationship.

In fact, the EDVAC will have an internal high-speed memory capacity for about 2,000 ten-digit decimal numbers, while the ENIAC accomodates only 20. Nevertheless, the EDVAC is expected to require only one-tenth as much equipment as the ENIAC. As a consequence, the solution of wide classes of non-linear partial differential equations will be easily managed in the EDVAC, whereas such problems can be carried out on the ENIAC only with the aid of a much slower external memory capacity in the form of punched cards.

Another important contrast between the ENIAC and the EDVAC is this: To change over from one type of problem to another, the ENIAC must be prepared by setting numerous switches and plugging in many interconnecting cables, while the EDVAC will be set up automatically and electronically for each new problem. Indeed, the EDVAC will store its operating instructions in exactly the same manner as it stores numbers. The total storage capacity will be at the disposal of the operator to allocate as he wishes— part to operating instructions, part to tables of functions, and part to the numbers which enter into and come out of the various calculations.

The input and output devices for the two machines are also different. The ENIAC reads from IBM cards, and results are punched into IBM cards. It is expected that the EDVAC will read from a steel wire or tape on which the required information has been recorded by magnetic means, and that the output data will be magnetically recorded on steel wire. Typewriters for preparing such wire and for printing from wire records will be provided. Records on steel wire are less bulky and more easily and automatically handled than stacks of separate cards. Also, higher reading and recording speeds are attainable with steel wire than with cards or with paper tape. Sorting problems, for which cards have always been considered desirable, are also done expeditiously using wire.

The EDVAC will be, then, a mathematical tool of much greater power and scope than the ENIAC. At the same time it will be physically smaller and easier to service.

Finally, much attention has been given to the question of "coding the problem" so as to simplify the work of the mathematician who must "instruct" the machine as to what he wants done in symbols which the machine "understands". On this topic and many others the project staff at the Moore

School has benefited greatly from conferences with and work done by Dr. John von Neumann, acting as consultant to the Ballistic Research Laboratory.

In Table 1 are some comparative figures for the ENIAC and the EDVAC. The figures for the EDVAC are estimated on the basis of the tentative plans outlined in Part 7 of this report.

1.2 SUMMARY OF REPORT

The earlier sections of this report are given over to a general discussion of complex computing machines, with emphasis on the way in which such machines employ memory devices, serial scanning procedures, and programming methods. This approach indicates that a machine of the necessary generality, capacity, and accuracy can be realized without excessive and unreasonable amounts of equipment if (a) "scanning" is employed so that one piece of equipment can be used many times rather than having many similar components working simultaneously, (b) the speed lost by this serial process is regained by employing electronic elements, and (c) accuracy is insured by digital methods, as, for instance, by the use of vacuum tubes as on-off devices, rather than as continuous variable devices.

Although serial use allows computing and switching equipment to be reduced to a minimum, the large storage capacity which is essential for numerical data, operating instructions and function tables would involve prohibitive amounts of electronic equipment if decade rings, binary counters, or other previously known methods were employed. A new and inexpensive memory device, the delay line register, conceived by J. P. Eckert and J. W. Mauchly in 1943, makes it possible to realize with a small amount of equipment the memory capacity needed for the EDVAC. The essential features and operation of this device are explained in Part 3.

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TABLE I

Comparative figures for the ENIAC and the EDVAC

NOTE: As explained in the text, the work of arranging or coding problems for solution by the EDVAC will be simpler than for the ENIAC, and the physical set-up of the EDVAC will be automatic, while there are 5000 manual switches and hundreds of cords to be plugged in manually in order to set up the ENIAC.

	ENIAC	EDVAC
<u>MEMORY CAPACITY</u> (each unit is one nine or ten digit decimal number, or one program instruction)		
Auxiliary memory	Unlimited, on IBM cards	Unlimited, on magnetic wire or tape
Internal high speed memory	20	Over 2000
Manually set up programs and function tables	725	0
<u>SPEED OF OPERATION</u> in milliseconds (9 or 10 digit decimal numbers)		
Addition	0.2	0.06
Multiplication	2.6	1.0
Input from auxiliary memory	35	3 to 6
Output to auxiliary memory	70	3 to 6
<u>EQUIPMENT</u>		
Vacuum tubes	18,000	1,925
Manual switches	5,000	Possibly a few
Digit and program channels	200	2
Power supplies	28	3
<u>SPACE REQUIREMENTS</u> (Sq. ft.)		
Floor area actually occupied by machine	250	25
Minimum area of room to allow access to machine	1500	125

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The high computing speed of the EDVAC would be largely wasted if conventional input and output devices were used. A new method, using magnetic wire or tape, has therefore been examined and found to meet EDVAC requirements. Input and output devices of this type are described in Part 4. A discussion of sorting and collating is included to show that magnetic wire devices are better for this purpose than existing card machines. Typewriters for preparing magnetic records and for printing from magnetic records are also discussed.

Part 5 contains a brief description of all of the principal components which will be used in the EDVAC. These are the memory units, the computer and the controller, electronic switches, the magnetic input and output devices, an oscilloscope unit for visual output, the power supplies and auxiliary devices such as typewriters.

Some desiderata for coding are presented in Part 6, which also contains an instruction code suggested by von Neumann and a proposed numerical code.

Plans for the EDVAC are presented in more detail in Part 7. These plans are tentative, and will be modified as the design is advanced. For the purpose of this report, it was decided to present plans based on use of a coded decimal number representation, although a binary system may ultimately be used. The computer elements are therefore somewhat more complicated than they would be for a binary machine. Two different plans for switching connections and corresponding pulse codes for orders are given to illustrate ways of organizing the components of the EDVAC.

In part 8 the reliability of electronic components and the methods which should be used for detecting failures in the EDVAC are given careful consideration. Until electronic digital computers are in use, and pertinent failure statistics become available, it is difficult to know how elaborate checking methods must be. It is therefore proposed that the EDVAC have a rather complete checking system which will guarantee the detection of almost all failures. This system checks all standard operations automatically, without instructions from the operator. Since the operator may always instruct the machine to perform further mathematical checks, full confidence in the accuracy of EDVAC solutions is assured.

In conclusion, it is intended, as stated in Part 9, that additional reports will be issued to supplement this one, and that some of these reports will give examples of how specific problems would be handled by various proposed instruction codes.

the same order of magnitude. For various reasons, the cards may have to be used inefficiently (only half filled, say) while this is not true of thw wire. Hence cases can arise where this spool of wire is the equivalent of 100,000 cards. The weight and bulk of this many cards is very large compared to the weight and bulk of the wire and spool.

This is an important consideration for storage purposes, but it is also important in the way if affects calculating and sorting operations. Handling 50,000 or 100,000 cards, and seeing that they are fed into and taken out of a card machine, is to be compared to placing several spools of wire in magnetic devices which thereafter operate automatically. Cards may easily get shuffled out of their proper order, while the information on the wire is not subject to such accidents.

4.5 SORTING AND COLLATING

4.5.0 The Need for Sorting and Collating

Sorting and collating are not always thought of as computing operations. Nevertheless, there are numerous ways in which a need for these operations may arise in the course of computing problems. Consequently, it is important to consider how sorting and collating can be done efficiently and at high speed.

It is a common notion that machines which employ cards are peculiarly suited to this work--and that tape machines are inherently at a disadvantage. This belief has been encouraged by the fact that commercially available tape devices are much inferior to card machines for sorting and collating.

If during a computing problem certain sets of numbers which are held in the high-speed memory must be sorted or collated, it is obvious that this should be done within the machine if possible. There is, in fact, no obstacle to this, and it is relatively simple to provide the controls and instruction code to take care of such situations. <u>It is estimated that the sorting and collating speeds attainable within the computer will be consider-</u>

ably higher than those now achieved by card machines.

Given that the machine is thus equipped to do "internal sorting", and "internal collating", it is tempting to think that the general problem has been solved by the expedient of transferring all tape information to the machine, doing the job within the high-speed electronic part, and then putting the results back onto the tape. This "solution" is, in fact, quite inadequate for large sorting jobs, since the memory capacity of the electronic machine is necessarily limited, while the number of cards (representing the memory) which may be processed by a card sorter is essentially unlimited. The magnetic wire or tape is the corresponding unlimited memory for the electronic machine, and sorting and collating processes must be devised which will utilize this memory without being restricted in any way by the limitations of the internal high-speed memory.

4.5.1 Tape Versus Card Sorting

The essence of sorting and collating is to take information which is arranged in one order (which may be random) and rearrange it in some other order. When the information is punched into cards, the information is "moved" from one place to another by moving the card which carries that information. When paper tapes are used, this method is no longer feasible, and the information itself must be moved by perforating the same information into a new tape. The only inherent disadvantage of this process is that the old tape may be of no use, so that in each such transfer of information, paper is wasted. A large number of transfers may have to be made before the sorting process is completed, so that the wastage is by no means unimportant. Magnetic tape or wire, on the other hand, immediately overcomes this problem since it can be erased and used for new storage as often as may be desired.

The fact that sorting is done more slowly with paper tape than with cards has nothing to do with the fact that one medium is "continuous" while the other is "discrete". The problem is solely that of how fast the information can be "moved". It so happens that commercial devices using paper tapes move the tape intermittently, reading it while at rest, and then advancing it to the next reading position. Also, such tapes usually have only five or six channels, while cards have 80 or 90 columns. As brought out in Section 2.9.2, paper tape devices of this sort have an effective rate of one thousand or more pulses per second. The great speed advantage of the card device over the paper tape device comes not from any inherent property of cards as opposed to tapes but from the fact that (a) card machines have many more channels, and (b) card machines have been designed with speed in mind, while the paper tape machines have been designed to work with other equipment which is also slow — for instance, a serial typewriter.

(Much higher speeds are known to be possible in devices which read paper tape photoelectrically. It is likely that perforating speeds could be increased, but not to the same extent. A single channel of a card punches holes at an approximate rate of 30 per second, while a single channel of a paper tape machine ordinarily punches 5 holes per second.)

Since a magnetic wire or tape device can, through a single channel, read or record at least 5000 pulses per second, information can certainly be moved from one place to another at least several times faster by these means than by card machines, in spite of the fact that the latter use 80 or 90 channels. Since this is so, sorting and collating should be done with magnetic devices rather than with card machines.

4.5.2 A Binary Sorting Device

The type of equipment which is needed for sorting and collating will now be described. The most elementary sorting process is one in which a single class of data is separated into two classes. This may be called binary sorting. The corresponding binary collating operation is that in which two ordered classes are meshed together to form a single ordered class. All more complicated cases of sorting or collating may be performed by a sequence of such binary processes. (It may be noted that card machines usually have binary collators, but use decimal, or even twelve or thirteen-pocket sorters.) At least three tapes or wires are needed in order to carry out these binary processes easily, without recourse to an extensive additional memory device.

Let it be supposed that a single magnetic wire contains a series of words which represent numbers, and that these numbers are in random order. It is desired to arrange them in "natural order", that is, in monotonic sequence. If each number is specified in terms of its binary digits, then the first step is to sort on the units digit. That is, as successive numbers are read from the original wire, all odd numbers are to be recorded on one wire, and all even numbers on another. This is accomplished by passing the pulse trains from the reader through an electronic discriminator circuit which then gates each word to the proper recording station, the proper gate being selected by the presence or absence of a "one" in the units place of that word. At the end of this operation, the original wire will have been erased (unless there is some reason for preserving the information in its original order for other work). Further binary sortings are now required (on successive digit positions), and two "clear" wires must be available. This could be arranged by transferring all the odd numbers to the oven wire, or vice versa, but such transfer is wasteful of time and can be avoided by providing four magnetic wires instead of three. It will therefore be assumed that four wires are used.

The second binary sorting process can then be begun by reading from the wire having odd numbers, and discriminating on the second rather than the units digit to determine which of the two free tapes will receive each word. After all of the odd numbers have been classified in this way, the even numbers are likewise classified by their second digits. They are recorded on the same two wires, but since they follow the odd numbers, the result of the first sorting has not been lost. At the end of this sorting process, there will again be two wires "clear", and sorting on the third digit can be carried out in a similar manner. Words consisting of N binary digits can therefore be arranged in monotonic sequence by N binary sortings, and during each such sorting these words are transferred from one wire to another at the rate of 5000 or more pulses per second.

It is in operations such as that just described that the practical necessity of being able to start and stop the wire or tape is keenly felt. Were every wire to run continuously (except for reversal at the end of each binary sort) then each binary sort would result in doubling the length of wire needed to hold the data. To waste wire in this way is undesirable, but of even greater importance is the fact that the time required for completing each sort is proportional to the length of wire which has to be fed through, whether that wire is blank or not. Furthermore, in cases where the original data occupied an entire spool of wire, then even more time would be wasted because many spools of wire would have to be handled by the operator before the job was finished. However, the servo devices to be discussed in section 4.6 overcome such difficulties. Whichever wire is not being used at any moment is at rest, and no blank spaces occur. The total length of wire occupied by the data after N binary sortings is equal to the length of wire occupied by the data in its original form. Each binary sorting therefore takes the same length of time as any other.

4.5.3 Sorting Speed

It is now possible to make some remarks concerning the speed with which sorting may be done by magnetic wire methods and compare this with card speeds. As a conservative estimate, take 5000 pulses per second for the rate at which information is transferred by magnetic devices, and assume that this figure already allows for the acceleration and deceleration times. (The justification for this is in Section 4.6) Further assume that a "full card" carries 80 decimal digits, that each digit is equivalent to four binary pulses, and that a card sorting machine will handle eight cards per second. Thus information is passed through a card sorter at about 2500 pulses per second when the cards are completely filled. The binary sorting device using magnetic wire passes information at twice this speed, but four binary sortings are necessary to equal one decimal sorting. Hence in this case the single-channel magnetic sorter is only half as fast as the 80-channel card sorter.

This comparison is, however, biased in several ways. In the first place, a very conservative figure has been used for the magnetic device, while the card device has been favored by assuming that the cards were completely filled. If the cards were only half filled, and the magnetic device were operable at 10,000 pulses per second, then the magnetic wire sorter would be twice as fast as the card sorter. Further, this comparison has neglected the fact that the magnetic wire device is fully automatic in operation, whereas the volume of data which can be placed on one spool of wire might require 100,000 cards, so that an operator would be kept busy several hours attending to the card sorter. Furthermore, if sorting is to be carried out on more than one card column, or decimal digit, a great deal more card handling is necessary. This not only takes time, but introduces the possibility of errors on the part of the operator. Finally, if the required sorting is in fact binary rather than decimal (as for instance, in sorting out all cards with an X punch in a certain column) an additional factor of four favors the magnetic device.

Taking into account the considerations of the preceding paragraph, it appears reasonable to state that there would be very few if any sorting problems which could be done as fast on the card machine as on the magnetic wire device. For all sorting problems involving a large volume of data, the card machine would probably be slower because of the time lost in manual manipulations, and would certainly be slower when the cards were not filled or nearly filled, or when binary or non-decimal sorting was sufficient.

Although in most cases considerably less than the total capacity of a card is needed to record all of the information which is to be sorted as a unit, problems do arise in which the capacity of a single card is insufficient. If more complicated coding systems are used to enable more information to be put on the same card, new sorting difficulties usually are introduced. On the other hand, if two cards are used instead of one to obtain the needed capacity, the sorting and handling problem is doubled. In contrast to this, no complications or new procedures are introduced in the magnetic wire sorting method by lengthening the information groups. The only result of having larger "units" of information to sort is to lengthen the sorting time in proportion. Thus cases may occur for which the carrying of slightly more information through the sorter will double the card sorting time but hardly affect the wire sorting time.

4.5.4 Systematic Sorting

In the previous sections, the material to be sorted was assumed to be in random order. Sorting machines are often used for processing systematic data. A simple example would be the transposition of a non-symmetrical matrix. A more complicated example occurs in the numerical solution of partial differential equations with three independent variables--say, two space variables and one time variable. The calculations for the mesh-point $(x, y, t + \Delta t)$ demand information concerning not only the previous results for point (x, y, t) but also the spatial neighbors of this, such as $(x + \Delta x, y + \Delta y, t)$ and $(x - \Delta x, y - \Delta y, t)$, etc. If the internal memory capacity of the computing machine is not large enough to retain all such prior data for many mesh-points, then the external magnetic wire memory must store this information. The various quantities which are needed for calculating the solution at $(x, y, t + \Delta t)$ will originally have been recorded on quite different parts of the wire, but in some systematic way. A systematic rearrangement, or sorting, may be desirable in order to assemble the quantities needed for the next step. However, it will usually be found that with proper use of four input-output devices, there will be no need to rearrange the material on the wires. But if, for any reason, such rearrangement must be done, it can be done more quickly and automatically using wire than using cards.

4.5.5 Collating

The device described in Section 4.5.2 as a binary sorter can function also as a binary collator. One output wire can record information which has been selected from one or the other of two input wires according to any desired plan. A systematic collation might require that N words be taken from one input, the M from the other, then N from the first, and so forth. There is obviously no difficulty in doing this. Often, however, a monotonic collation is needed. In this case, each input tape contains data in monotonic sequence, and it is desired to "mesh" these to form a single monotonic sequence in the output. Each group of words to be transferred as a unit contains a "key word" according to which the various units are ordered. The collator must compare the key words from the two inputs and determine which of the two units of input data is to be recorded next on the output wire. A comparing circuit (see Section 7.6.6) is able, within one or two minor cycles, to determine which of two numbers is the larger. This time is negligible relative to the time required for reading or recording one word on a wire.

Hence any sort of collating, systematic or monotonic, can be carried on at the speed with which the magnetic wire device can transfer information, that is, at a rate of 5,000 or possibly 10,000 pulses per second. Card collating machines are not nearly as rapid as card sorting machines. Moreover, they are binary while sorting machines have as many as thirteen pockets. In comparing sorting speeds, four binary runs on the magnetic wire device were needed to accomplish what is done with one run on the card machines, but in comparing collating speeds, one run on the magnetic wire device accomplishes exactly the same thing as one run on the card collator. It therefore appears that, taking into account only the rate at which information is transferred, the magnetic wire collator must be at least five times faster than the card collator. If the cards are incompletely filled, or if the wire device can be developed to work at more than 5000 pulses per second, the speed ratio might become ten or twenty.

The discussion of sorting and collating speeds given in the various subsections of 4.5 has been concerned with magnetic wire devices to handle volumes of data which far exceed the high-speed memory capacity of the EDVAC itself. It should be emphasized again that, when the data to be sorted or collated exist entirely within this high-speed memory, then much higher rates are obtainable.

4.6 SERVO CONTROL FOR MAGNETIC RECORDING

The need for rapidly starting and stopping magnetic wire or tape was brought out in Section 4.5.2. Although devices for doing this have not so far been developed, since commercial sound recording does not require this, servo motors are now obtainable with suitable performance characteristics for this purpose. It is expected that a small motor, with high torque-inertia ratio, will be used to drive that part of the wire which is passing through the recording, reading, and erasing positions. Other servo motors, which need not have as rapid response, can then drive the spools in such a way as to maintain approximately the desirable amount of "slack". It is estimated that the time required to bring the wire from zero speed to recording speed might be one or two milliseconds or even less.

4.7 TYPEWRITERS

Auxiliary devices must be provided for preparing the magnetic records which are to operate the EDVAC, and for automatically printing or typing the output data which the EDVAC records on magnetic wire or tape. Automatic typewriters are now commercially obtainable which will serially type 12 to 18 characters per second and these could be adapted so as to read from magnetic wires or tapes. Higher typing rates are now obtained by multiple equipment, as in the gang printing business machine tabulators which, working from cards, print 80 to 100 characters simultaneously, and

6.3 THE ORDER CODE

At this point, the general scheme now contemplated for the order code will be outlined. As a practical matter, questions concerning what should be included, and what should not be included, in the system of orders depends upon how many long tanks and how many short tanks are available, what time durations are expected for various operations, and the importance of those various operations in calculating. The decision as to how many pulses make up one word also has a direct effect on the order code, by limiting the information which may be put within one order.

Pulse codes for orders will be taken up in Section 7.3 in conjunction with certain specific suggestions as to switching and control methods. The type of orders which are considered desirable, and which such pulse codes ought to be capable of representing, are given in the list below. This plan for orders is essentially that which von Neumann has proposed after trying out various coding methods on typical problems. His notation, and an equivalent one which uses only ordinary typewriter symbols (in accordance with Section 6.0) are given in parallel columns.

Code Symbols (von Neumann)	(Suggested)	Meaning
z	z	Denotes a long tank
$\bar{x}$	x	Denotes a short tank
$\rightarrow$	t	Transfer to
$\ominus\!\!>$	u	To be replaced by
$z \rightarrow \underline{\bar{x}} / \underline{r}$	ztxn	Transfer r consecutive numbers in tank z into the tanks x, x+1, x+2, ..., x+r-1. If this exhausts tank z then move on to tank z + 1
$\bar{x} \rightarrow \underline{z} / r$	xtzn	Transfer r consecutive numbers stored in short tanks x, x+1, ..., x+r-1, into the tank z and if necessary into tank z+1.
$c \rightarrow z$	ztp	Connect control to long tank z
$c \rightarrow \bar{x}$	xtp	Connect control to short tanks x.
$x_1 \; w \; x_2$	$x_1 \; w \; x_2$	Send the numbers in short tanks x_1 and x_2 to the computer and perform the operation w (see below).
$\rightarrow \bar{x} / r$	txn	Transfer the "next" r words into short tank x, x+1, ..., x + r-1.
$\rightarrow z / r$	tzn	Transfer the next r quantities into tank z.
$o \rightarrow \bar{x}$	qtx	Dispose of the computer result to short tank x.

The operations denoted by w are

$+$	a	Addition
$-$	s	Subtraction
$\cdot$	m	Multiplication
$\div$	d	Division
s	c	Compare (determine which of two numbers is larger, and make some choice of orders to be carried out, depending on the outcome)
$\sqrt{}$	r	Square root (possibly this operation will not be included in the fundamental one above, but will be a subroutine stored in the memory)

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Von Neumann has specified that some order symbols be capable of modification by deleting a given part of the order and inserting something else in place of this part. This allows for the substitution referred to in Section 2.9.4, so that function tables may be used, subroutines called in, etc.

Several necessary symbols are missing from the above list: those are concerned with ordering the input and output devices to operate.

From examination of the above list in connection with particular pulse code possibilities, it appears that the designation of an operation (exclusive of designating x and z numbers) will require selection from more than 16 but less than 32 possibilities. Thus only 5 pulses would be necessary to make such a selection.

PART 7 TENTATIVE PLANS FOR THE EDVAC

7.0 NUMBER AND ARRANGEMENT OF COMPONENTS

A tentative plan for the EDVAC is illustrated in Fig. 3. As represented on this drawing the machine consists of the units listed in Table 3.

Another possible arrangement is Fig. 4, the interesting feature of which is the fact that all the units are on terminals of the switches which choose the memory tanks. In contrast to these plans the machine could consist of 64 long tanks, 32 short tanks, and the various other units all connected to a trunk system and the necessary isolation provided by a number of gate tubes.