NRL REPORT 3714

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PROPOSED DESIGN OF THE NRL ELECTRONIC DIGITAL COMPUTER

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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PROPOSED DESIGN OF THE NRL ELECTRONIC DIGITAL COMPUTER

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NAVAL RESEARCH LABORATORY

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ABSTRACT

A general-purpose, electronic digital computer (called NAREC) will be constructed at the Naval Research Laboratory for use in the reduction of experimental data and in the numerical solution of complex mathematical problems. Since this computer will be of the parallel type, it should perform automatically the operations of addition, subtraction, multiplication, and division with binary numbers of 44-digit precision at a rate of 9000 operations per second. The input and output circuits are to be operated from magnetic tape and will handle decimal numbers of 11-digit precision. An electrostatic storage for 1024 words (that is, either numbers or operational instructions) and an auxiliary magnetic-drum-type storage for 2048 words will be provided. As now planned, the computer will include about 1800 vacuum tubes and 6000 crystal diodes. It is expected that the computer will be completely installed at NRL by January 1952, although it will probably be six months later before system operation will have been completely checked.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem R10-60R
NR 510-600

PROPOSED DESIGN OF THE NRL ELECTRONIC DIGITAL COMPUTER

INTRODUCTION

The Naval Research Laboratory Electronic Digital Computer (the NAREC) is to be a general-purpose, electronic digital computing machine capable of high-speed computations with binary numbers having a precision of forty-four digits (about thirteen decimal digits). The high-speed and precision characteristics of the NAREC will make it especially valuable not only for reduction of experimental data but also for the solution of systems of linear equations with a large number of unknowns, nonlinear differential equations, and other problems involving computations of a similar magnitude. The input-output circuits will be capable of inserting or extracting decimal numbers having a precision of eleven digits. Transfers of numbers within the computer and the basic arithmetic operation of addition are to be performed with parallel-type circuits. This type of circuit will enable the NAREC to perform transfers and the four arithmetic operations of addition, subtraction, multiplication, and division at an average rate of 9000 operations per second. Approximately 1800 vacuum tubes and 6000 crystal diodes will be required to provide these operating characteristics. Operational instructions to accomplish the numerical solution of a given problem will be inserted as input information and retained within storage circuits. During the automatic operation of the computer these instructions will be interpreted in the proper sequence by control circuits which will initiate the specified operations.

The NAREC was undertaken as the result of a recommendation by a committee formed by the Director of NRL in April 1948 to investigate the computational requirements of the Laboratory. In a report submitted in May 1948, this committee recommended that the existing computational facilities of the Laboratory be implemented by the addition of both an analogue and an electronic digital computer. Subsequently, the Director assigned Radio Division III the responsibility for the procurement and the operation of the digital computer. In the months following this assignment, personnel of the Operational Research Branch (Radio Division III) surveyed the work being done in the field of digital computers. On the basis of this survey, the decision was reached to have the design and construction of the required machine undertaken by personnel of the Branch. Accordingly, NRL Problem R10-60R was established in January 1949; but because of a shortage of personnel, the design of the NAREC was not begun until July of that year. Although continued personnel shortages have interfered with progress of the project, it is expected that the situation will be much improved in the near future.

GENERAL DESCRIPTION

The circuits of the NAREC (Figure 1) are divided into the following five sections:

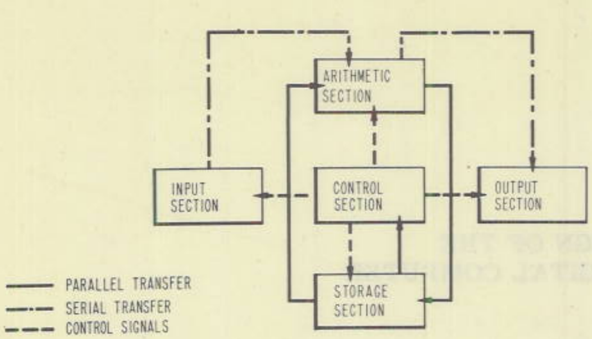

Figure 1 - Block diagram of the computer

1. Input Section
2. Arithmetic Section
3. Storage Section
4. Control Section
5. Output Section

In addition, equipment is provided for preparing the magnetic tapes used by the Input Section and for transcribing the information recorded on magnetic tape by the Output Section. The Input Section contains circuits which read information from a magnetic tape and transfer it serially to the Arithmetic Section. The input information is transferred in a parallel manner from the Arithmetic Section to particular storage locations in the Storage Section. Circuits of the Storage Section are capable of retaining information as long as may be required. The transmission of information from a particular storage location does not erase the information from that location. After the computer has received all input information (numbers and operational instructions), the Control Section provides for the automatic operation of the computer. Operational instructions are extracted from the Storage Section as required by the Control Section. The Control Section interprets these instructions and activates circuits within the other sections of the computer to accomplish the desired operations. Numbers are transferred in parallel from the Storage Section to the Arithmetic Section and from the Arithmetic Section to the Storage Section. The Arithmetic Section is capable of performing the arithmetic operations of addition, subtraction, multiplication, and division. The results of computations are transferred to the Output Section where they are recorded on magnetic tape.

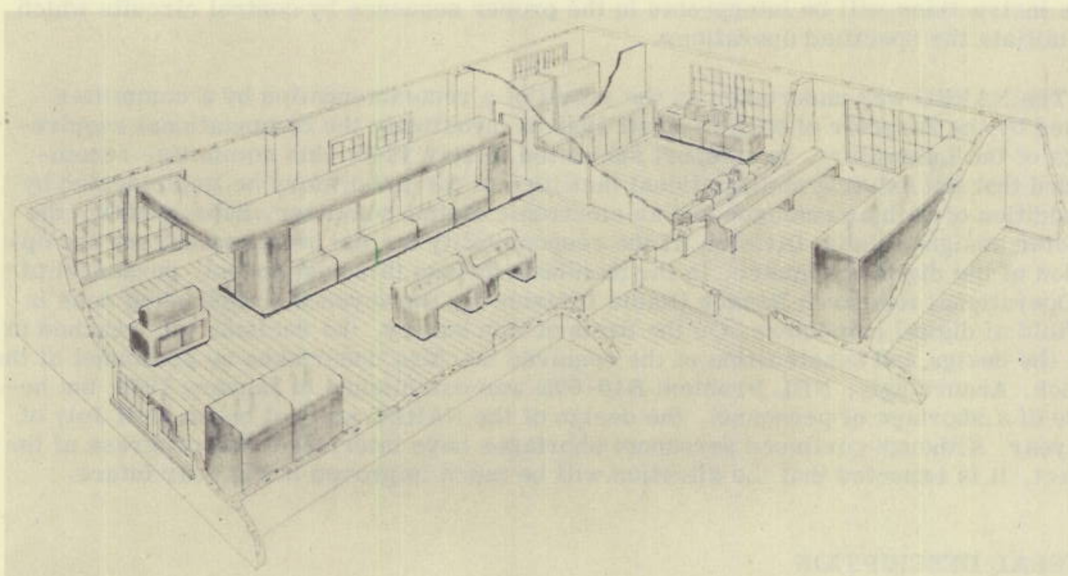

Figure 2 - Proposed arrangement of the computer and associated equipment

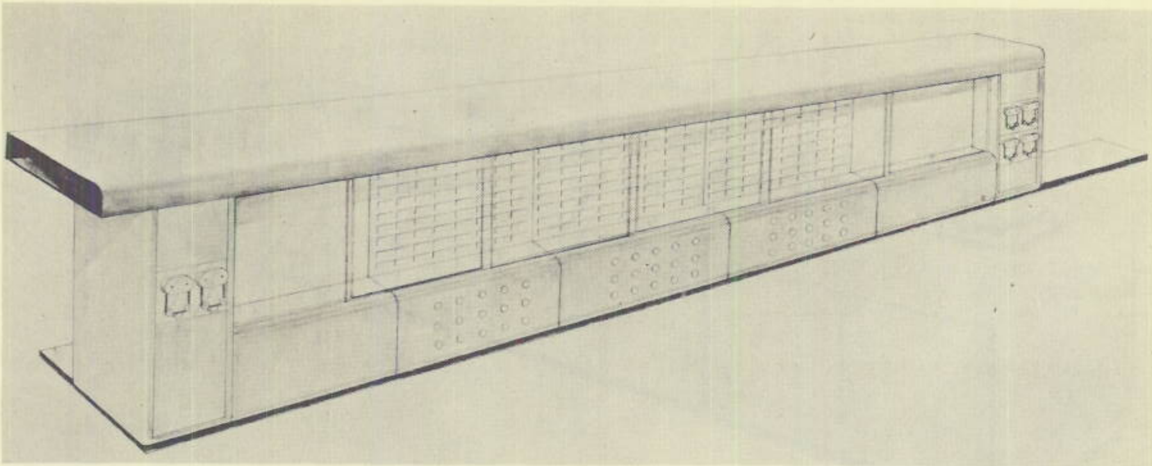

Figure 3 - Computer unit

A proposed arrangement of the NAREC, the necessary air-conditioning equipment, and the maintenance area is shown in Figure 2. The main room (26 by 42 feet) will contain the computer, magnetic-drum storage, control desk, and the necessary power supplies. The air-conditioning equipment will be housed in a separate room measuring 9 by 18 feet. The equipment for preparing and transcribing magnetic tapes will be placed in a room 17 by 18 feet. Adequate storage space for a reference library of punched-paper

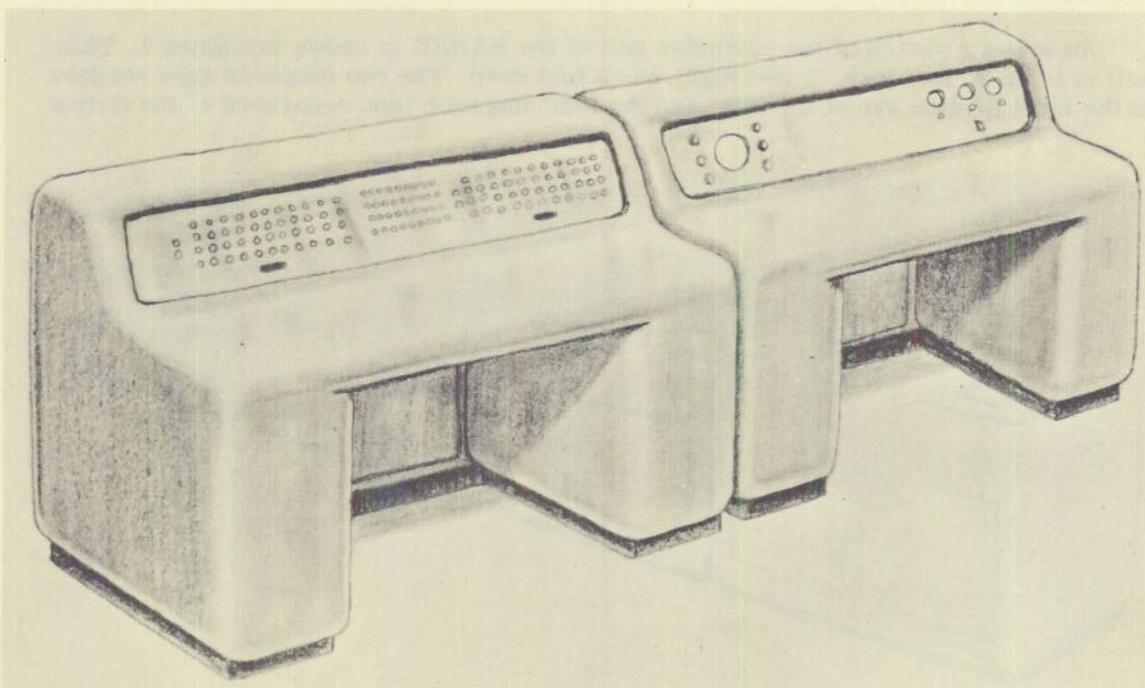

Figure 4 - Control desk

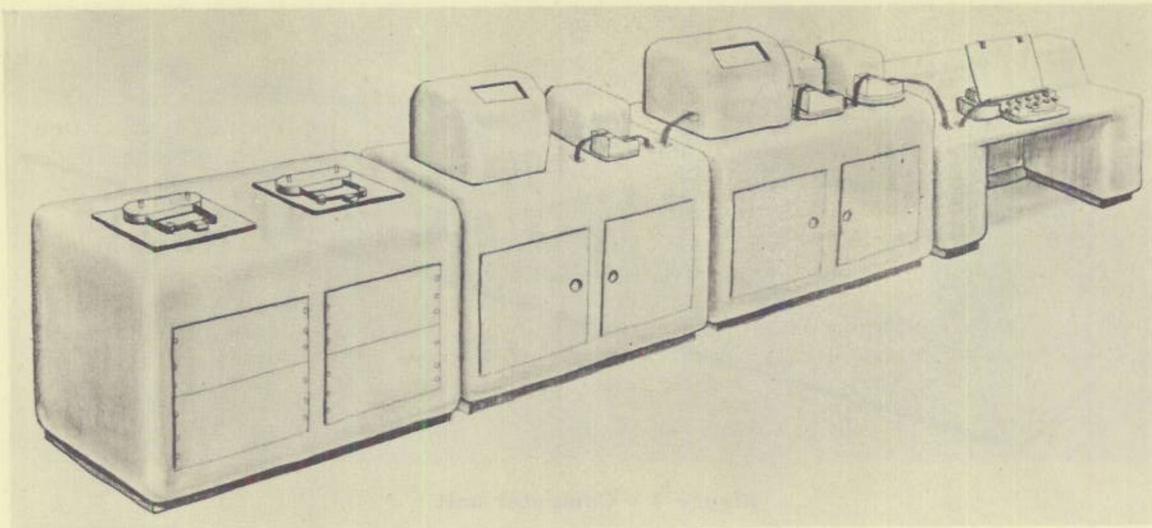

Figure 5 - Tape preparation equipment

and magnetic tapes is also provided in this room. A room measuring 15 by 26 feet will be required for maintenance work and spare parts storage. With this arrangement a total of 1850 square feet of floor space will be required for the installation of the NAREC.

An artist's sketch of the computer unit of the NAREC is shown in Figure 3. This unit is to be 30 feet long, 8 feet high, and 3 feet deep. The two magnetic tape readers of the Input Section are at the left, and the four magnetic tape recorders of the Output

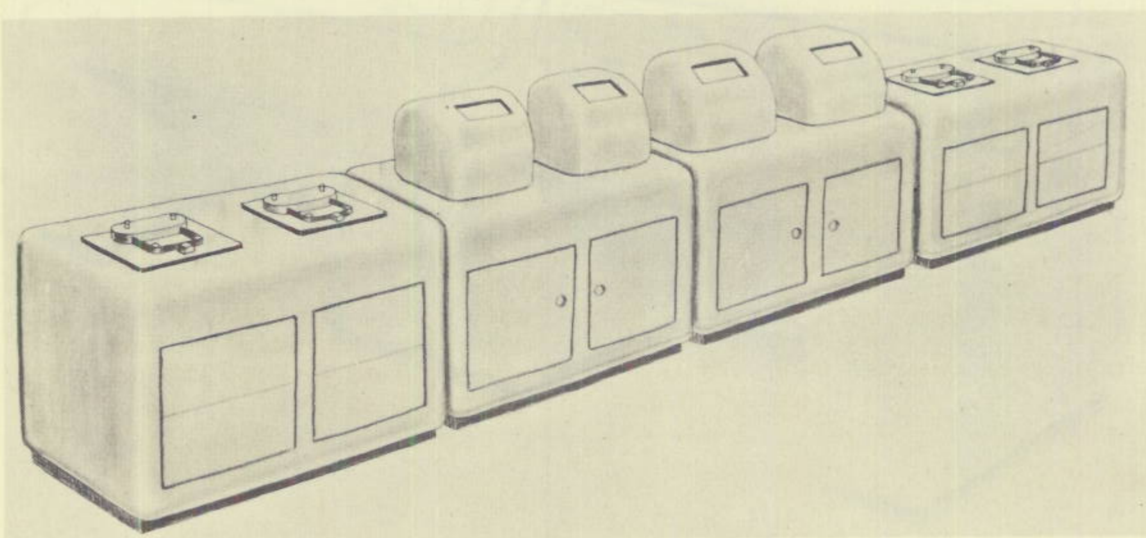

Figure 6 - Tape transcription equipment

Section are at the right. The cathode-ray tubes of the electrostatic storage extend along the bottom of the center portion of the unit, while the magnetic-drum storage is housed in a separate unit (not shown). Most of the 1800 vacuum tubes and 6000 crystal diodes are contained in the Control and Arithmetic Sections, and these elements are mounted in the center part of the unit above the cathode-ray tubes. All the circuits may be operated from the control desk shown in Figure 4. Switches and keys are provided for inserting or extracting numerical information and for inserting operational instructions. The cathode-ray tube shown at the control desk is used to monitor any one of the cathode-ray tubes contained in the electrostatic storage. Modified teletype equipment (Figure 5) is used to prepare and check a punched-paper tape containing the numerical and operational information to be inserted. A magnetic tape is then prepared from the punched-paper tape by the other equipment shown in Figure 5. Similar equipment is used for transcribing the computer-output information from the magnetic tapes of the Output Section (Figure 6).

COMPUTER WORD

The circuits of the NAREC are arranged to handle sets of forty-five binary indications, that is, each of the forty-five positions in the set may assume either the value unity or the value zero. This set of binary digits is defined as a word. A word may be either a number or an operational instruction, since a number and an instruction differ only in the manner in which the computer circuits make use of them. A number is either a forty-four binary-digit number with sign, or an eleven decimal-digit number with sign. For a number in either notation, the decimal point is fixed immediately after the first digit, which is the sign indicator; thus, all numbers used by the computer must be of absolute value less than one. In the case of decimal numbers, each decimal digit is written separately in its binary equivalent. In this representation, a group of four binary indications is used to represent a decimal digit, and forty-four binary digits are required to represent an eleven decimal-digit number. Since all arithmetic operations within the computer are performed in the binary number system and most input-output information will be given in decimal notation, it is necessary to provide for binary-to-decimal and decimal-to-binary conversions. The conversion from one number system to the other may be reduced to a series of arithmetic operations; hence, it may be performed by the computer as a part of the prearranged computing routine.

A word is also used as an operational instruction. An instruction, or order, specifies the location of a number within the Storage Section of the computer and indicates the operation which is to be performed upon the number (usually by the Arithmetic Section). Since only twenty-one binary digits are needed to express this information, a word consists of two orders, namely, a left-hand order, and a right-hand order. Normally, the words representing operational instructions are stored as a block in the Storage Section; and, in beginning a computational routine, the Control Section selects the first word of the block. The Control Section causes the left-hand order of that word to be performed and then the right-hand order. Next, the second word of the block is selected by the Control Section, and its orders are performed as before. This process is continued until the words contained in the block have all been used.

THE COMPUTER

The five sections of the NAREC may be subdivided as follows:

Input-Output Sections

Magnetic Tape Reader
Output Register
Magnetic Tape Recorder

Storage Section

Electrostatic Storage
Magnetic Drum Storage

Arithmetic Section

A Register
B Register
U Register
V Register
Adder
Transfer Register and Inverter

Control Section

Program-Control Counter
Program Register
Storage-Location Selector
Operation Selector
Manual Control

These circuits are arranged in block-diagram form in Figure 7. Flow lines are shown between circuit blocks to indicate paths over which information may be transmitted and received. Each solid flow line represents the parallel transfer of a forty-five binary-digit word. A word is transmitted from one block to a second when the flow line connecting the two blocks is energized by a signal from the Control Section of the computer. A dot-dash flow line represents the serial transfer of information from a magnetic tape to a register or from a register to a magnetic tape. The dashed flow line is explained later in the discussion of the Arithmetic Section.

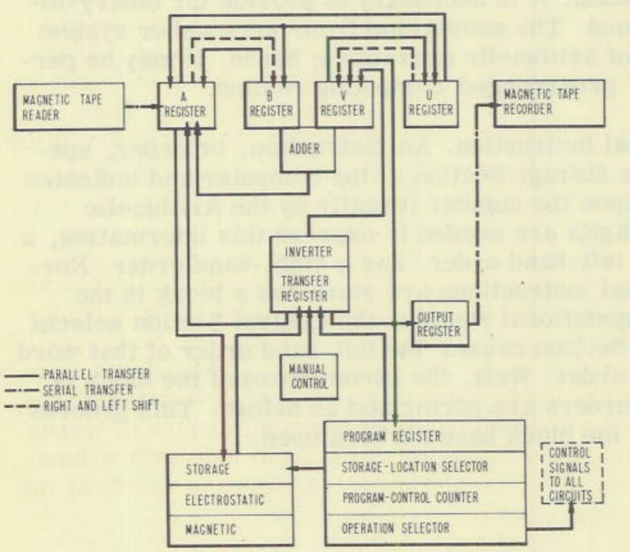

Figure 7 - Detailed block diagram of computer

Input Section

Before the NAREC may be placed in automatic operation, the necessary input information (numbers and operational instructions) must be inserted in the proper storage locations of the electrostatic storage. The input information is contained serially on a single channel of a magnetic tape which has been prepared by the tape-preparation equipment shown in Figure 5. The Input Section contains a magnetic tape reader which senses the magnetized pulses of plus and minus polarity on the tape and transmits corresponding binary indications to the A register of the Arithmetic Section. When the A register has received the forty-five binary digits of a word, the word is transferred in parallel from the A register to the electrostatic storage of the Storage Section. Words are placed in the electrostatic storage in sequential order: the storage-location selector of the Control Section is advanced one unit each time a word is registered in the electrostatic storage. The electrostatic storage provides for the simultaneous retention of 1024 forty-five binary-digit words. All or any part of this storage may be filled on the input operation from the magnetic tape of the Input Section.

Output Section

Words (generally, decimal numbers) may be extracted from the Storage Section and recorded on magnetic tape as part of the automatic operation of the NAREC. When it is desired to record the contents of a specific storage location, the word at that location is sent to the transfer register of the Arithmetic Section and is then transferred to the output register. The binary digits of the word are extracted serially from the output register and are recorded by one of the magnetic tape recorders. Following the transfer of the word to be recorded to the output register, the Control Section of the computer is allowed to proceed with the next operation, because the recording of information from the output register is independent of the other computer operations. When the recording of the word is complete, the output register is free to accept another word for recording. Circuits are provided for delaying a further print instruction if a number in the output register is in the process of being recorded.

The tape of the magnetic tape recorder is moved at a speed of thirty inches per second, and it is anticipated that a maximum of 75 pulses may be recorded in a given inch of tape. Since forty-five pulses must be recorded for each word (synchronizing and identification pulses are recorded on other channels of the tape), fifty words may be recorded on the tape during one second of computer operation. For problems suitable for solution on the NAREC, this recording rate appears to be adequate. Circuits are provided to introduce format-control symbols in the numerical information as that information is recorded on the magnetic tape from the output register. When this tape is later transcribed, the printing will be arranged in the desired column form. The printed copy of the data may be reproduced directly, and no further transcription of the data is required.

Storage Section

Two types of internal storage are provided in the NAREC. An electrostatic storage similar to that developed by Professor F. C. Williams of the University of Manchester (England) provides for the storage of 1024 words, any one of which may be made available to the Arithmetic Section of the computer in ten microseconds.* The second form of storage is of the magnetic-drum-type and provides for the storage of 2048 words. The magnetic storage serves as a reservoir for the electrostatic storage: groups of words are received or transmitted to the electrostatic storage as required. For such a function the magnetic storage need not be capable of receiving or transmitting words at the high speeds provided for in the electrostatic storage.

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* Williams, F. C. and Kilburn, T., "A Storage System for Use with Binary-Digital Computing Machines," Proceedings, Institute of Electrical Engineers (London, England), Volume 96, Part III, pages 81-100, March 1949

In the electrostatic storage, binary information in the form of dots or dashes of charge may be placed through the action of the electron beam within any one of a 32-by-32 array of locations, or cells, on the central portion of the face of the cathode-ray tube. An additional circuit (external to the cathode-ray tube) is capacitance-coupled to the face of the tube and is used to extract information through a process of detecting the change of total charge experienced by the face of the tube as the electron beam is focussed on a given location. A cathode-ray tube is provided for each of the forty-five digit positions, so that words may be inserted or extracted in a parallel manner from the electrostatic storage. Words to be recorded are transferred to the electrostatic storage from the A register, and words extracted from the electrostatic storage are sent to the transfer register. Beam positioning is accomplished by a current-adder device which receives a binary designation of the storage location from the storage-location selector of the Control Section. The positioning and the "read" or "record" operation require about ten microseconds. On the average, the phosphor of the tube face is not capable of retaining the complete pattern of charges placed upon it at any given time for periods much longer than 0.1 second. The pattern of charges must then be regenerated at that rate or more frequently if possible. The regeneration of the pattern is accomplished automatically whenever the electrostatic storage is not engaged in a reading or writing operation. A circuit is provided to halt the operation of the computer so that the regeneration cycle may be completed whenever there is danger that the cycle would not have been completed in the given period.

A magnetic-drum storage with a capacity of 2048 words serves as an auxiliary storage to the electrostatic storage. Since the drum rotates at a rate of 3600 revolutions per minute, a maximum of 1/60 of a second may be required for the location of a given word. Words are recorded on the drum in parallel from the A register of the Arithmetic Section and read from the drum into the transfer register. In addition to the forty-five information channels on the drum, twelve channels are used to identify the storage locations. When coincidence is detected between the location indicated by these twelve channels and the location specified by the storage-location selector, the indicated reading or recording operation is performed. Since the maximum time of slightly more than 1/60 of a second is excessively long for locating and reading or recording a single word, provision is made for transferring groups of 64 words from the electrostatic storage to the magnetic storage or from the magnetic storage to the electrostatic storage. The words of a group are read from successive locations in one type of storage and are recorded in successive locations in the other type. The initial storage location for each type of storage is specified in the operational instruction. The words are arranged on the magnetic drum in such a way that successive words are made available at intervals of 16 microseconds. The maximum time required for locating the first storage location and then transferring 64 words from one type of storage to the other is about 17,700 microseconds. The maximum transfer time per word is 276 microseconds, but on the average the transfer time per word is about 150 microseconds.

Arithmetic Section

The Arithmetic Section of the computer consists of five registers, an inverter, and an adder. The direct transfers which are provided among the five registers (Figure 7) are as follows:

From	A	to B and U
From	B	to A
From	U	to A
From	V	to U
From	Transfer	to A and V

In addition, connections (dashed flow lines of Figure 7) are provided between the A and B registers such that a word in the A register may be transferred to the B register shifted one binary position to the left or to the right. Similar connections exist between the U and V registers.

The B and V registers are connected directly to a parallel adder, which furnishes the sum of the contents of the two registers to the A register when the gates of the sum path are energized to permit the transfer of information. The circuits of the adder are of the diode-coincidence type, and the process of determining the sum of two forty-five digit binary numbers requires three microseconds. The inverter circuit, used in the process of subtraction, is connected directly to the transfer register and provides a 1-signal for those digits of the transfer register which are zero and a 0-signal for digits which are unity. The addition or subtraction operation requires about thirty microseconds. Provision is made for the use of absolute values in the addition and subtraction processes.

Multiplication and division are performed by the adder with the assistance of the shifting features of the A-to-B and U-to-V connections. In multiplication, the number in the U register is multiplied by the contents of a specified storage location in the electrostatic storage, and the 88-digit product is formed in the A and U registers. The multiplication process requires approximately 300 microseconds. In division, the contents of the A register are divided by the contents of the specified storage location in the electrostatic storage and the quotient is formed in the U register with the remainder in the A register. The division process requires approximately 400 microseconds. Both the multiplication and division processes may be performed with round-off in the product and quotient respectively to forty-four binary digits (excluding the sign digit). Provision for not rounding is made so that the multiplication and division operations may be extended more easily to double-precision computations (multiplying two 88-binary-digit numbers to obtain an 88-digit product, or dividing two 88-binary-digit numbers to obtain an 88-digit quotient).

Control Section

The series of instructional words corresponding to the desired sequence of operations for the NAREC is inserted into the electrostatic storage of the Storage Section as part of the input information. Before the computer is placed in automatic operation, appropriate switch-settings are made to give the program-control counter of the Control Section its initial value, namely, the storage location of the first operational-instruction word. Other circuits cause this first instruction word to be sent to the transfer register of the Arithmetic Section and then to the program register of the Control Section. The operation selector and the storage-location selector of the Control Section are connected to the left-hand order of the instruction word in the program register. The operation selector interprets the operation designation of the order and provides the initiating action for the operation required.

The storage-location selector is connected to the Storage Section and indicates the location of the number to be operated upon. Circuits of the Storage Section function to place the contents of the specified storage location in the transfer register of the Arithmetic Section. The further transfer or use of the number is then under the control of the operation selector of the Control Section. Upon completion of this first order, the operation selector and the storage-location selector are switched to the right-hand order of the instruction word contained in the program register of the Control Section. When this order has been completed, the program-control counter is advanced by one unit. The instruction word corresponding to the new value of the counter is extracted from the electrostatic storage and is transferred to the program register of the Control Section. With the new word in the program register, the operation selector and the storage-location selector circuits cause the performance of the left-hand order and then the right-hand order. This sequence of word selection and the performance of left- and right-hand orders is continued until the sequence of operational instruction words is completed.

A strictly sequential type of coding, however, is not flexible enough for the efficient solution of the mathematical problems for which the NAREC might be used. A special order is therefore provided for changing the program-control counter to a new value. This order is referred to as an unconditional transfer of control. It allows the Control Section to skip from one block of operational instructions to a second such block. After the order has caused the program-control counter to assume this new value, the counter is stepped ahead as before, i.e., one unit for each completed operational word. A similar special order permits the program-control counter to assume a new value only if the word in the A register is positive. This order is referred to as a conditional transfer of control. It provides for moving the program-control counter to a second block of sequential coding only if a certain condition exists.

Another special order provides that the storage location contained in a given order be replaced by a specified storage location. This is a change-of-address, or a substitution, order. All of these special control orders have been selected to make the coding of the NAREC as simple and as flexible as possible. It is expected that the number of operations which may be performed by the computer will be less than 32, although provision for 64 operations is made in the operation selector of the Control Section. The storage-location selector is capable of handling a maximum of 8192 storage locations, but only 3072 storage locations will be employed in the proposed design. The extra capacity of the storage-location selector provides for the possible expansion of the internal storage should an increase be found necessary. A listing of all of the operational instructions is given in the Appendix. These orders are accomplished over the flow lines of the block diagram of Figure 7.

A manual control feature is provided so that the NAREC may be operated from a central control desk (Figure 4). Operational instructions and numbers may be inserted as required through a set of switches and keys. This type of control is useful in setting up the NAREC for a given problem and in checking the various circuits of the computer. The contents of any register or storage location are available at the control desk through proper setting of the switches and controls provided.

TAPE PREPARATION EQUIPMENT

In the discussion of the computer it has been assumed that a magnetic tape containing the input information had been prepared and checked. The amount of equipment required for checking and preparing this magnetic tape is shown in Figure 5. In the present plan for preparing a magnetic tape, each of two operators types a punched-paper tape corresponding to the original manuscript. An automatic comparator then checks the punchings contained on one tape against those of the other. If the punching on the two tapes is the same, the comparator causes corresponding symbols to be recorded on a printer-perforator. If a point is reached at which the two tapes do not agree, the operator inserts the correct character from a set of keys on the comparator. The correct tape coming from the printer-perforator is then used to prepare a typed manuscript of the information represented by the punched tape. At the same time, the information contained on the punched-paper tape is recorded serially on a single channel of a magnetic tape. The serial train of positive and negative pulses recorded on the magnetic tape corresponds to the punch or no-punch information contained on the paper tape. In turn, the positive and negative pulses of the magnetic tape can be interpreted as zeros or ones when the magnetic tape is read by the magnetic tape reader of the computer. Synchronization and word identification pulses are also inserted in other channels of the magnetic tape at the same time the information is recorded. Rolls of 400-foot magnetic tape may be prepared by the tape preparation equipment. Since it is anticipated that 75 pulses per inch may be recorded, a roll of tape may contain a maximum of about 8000 words of forty-five pulses each.

TAPE TRANSCRIPTION EQUIPMENT

Four separate equipments are provided to transcribe magnetic tapes containing the results computed by the NAREC. A transcription unit consists of magnetic-tape playback equipment, a modified teletype printer, and the necessary circuits for linking the playback equipment with the printer. Format control information has previously been placed on the magnetic tape as the information recorded was extracted from the output register. The magnetic tape to be transcribed may contain a maximum of 8000 words, since it has the same characteristics as the tape prepared by the tape preparation equipment. Because a printer of the Output Section operates at a recording rate of six characters per second, the magnetic-tape playback equipment must supply the binary signals to the printer at that rate. This requirement means that information recorded at a tape speed of thirty inches per second must be detected by the playback equipment at a tape speed of about a third of an inch per second.

FUTURE PLANS

During the next six months a prototype model of the circuits of the Arithmetic Section will be constructed. This unit will operate with a precision of six binary digits and be capable of addition, subtraction, multiplication, and division. The circuits of the unit will be based upon breadboard designs of registers, gates, and an adder, all of which have already been constructed and partially tested. The prototype model will be used to check the operation of the circuits, to determine the circuit configuration to be used in the final assembly of the circuits, and to test the circuits of the Control Section on a preliminary basis. It is intended to maintain this unit in automatic operation as long as may be required to obtain statistical information concerning the frequency, kind, and type of circuit failures. Preliminary tests of the magnetic drum storage unit should begin in May 1951. These tests will include an investigation of the circuits required to transmit and receive information from the prototype model of the Arithmetic Section. The tape preparation and tape transcription equipment will be assembled as time permits during this year.

As circuits are checked and given final approval, they will be constructed and placed into the main framework of the NAREC, but it is estimated that this work will not begin on any large scale before July 1951. Work on the electrostatic storage will be continued, but it is expected that the computer will first be placed in operation and completely tested with only the magnetic drum type of storage in operation. Final design checks should be completed and assembly of the electrostatic storage begun in September 1951. It is hoped that the NAREC will be placed in operation by January 1952 with the following six months being required to place the computer on an efficient operating schedule.

ACKNOWLEDGMENTS

Since the previous work in the field of automatic computers is considerable, it is impossible to give detailed acknowledgment of the source of many ideas contained herein. The reports issued by the Computer Project of the Institute for Advanced Study (Princeton, N. J.) have been of particular value. The assistance of associates and others is gratefully acknowledged, and especial credit is due Mr. E. W. Peterkin (Equipment Research Branch, Radio Division III) for the artist's sketches of the NAREC.

* * *

APPENDIX

Operational Instructions for the NRL Electronic Digital Computer

Operation Number	Coding Symbol	Order Modifications
00	Lo(s)	Transfer the control to the left-hand order of the word at storage location s.
01	Ro(s)	Transfer the control to the right-hand order of the word at storage location s.
02	CL(s)	If the sign digit of the word in the A register is zero, transfer the control to the left-hand order of the word at storage location s.
03	CR(s)	If the sign digit of the word in the A register is zero, transfer the control to the right-hand order of the word at storage location s.
04	LAL(s)	Replace digits 0 through 12 of the word at storage location s by digits 0 through 12 of the word in the A register.
05	LAR(s)	Replace digits 24 through 36 of the word at storage location s by digits 0 through 12 of the word in the A register.
		Transfer Operations
06	s A	Transfer the word at storage location s to the A register.
07	-s A	Transfer the negative of the number at storage location s to the A register.
08	|s| A	Transfer the absolute value of the number at storage location s to the A register.
09	- |s| A	Transfer the negative of the absolute value of the number at storage location s to the A register.
10	U A	Transfer the number in the U register to the A register.

Operation Number	Coding Symbol	
11	s U	Transfer the number in storage location s to the U register.
12	A U	Transfer the number in the A register to the U register.
13	A s	Transfer the word in the A register to storage location s.
14	U s	Transfer the number in the U register to storage location s.
15	E(s) M(t)	Transfer the 64 words in storage locations s to (s + 63) in the electrostatic storage to locations t to (t + 63) in the magnetic drum storage.
16	M(t) E(s)	Transfer the 64 words in storage locations t to (t + 63) in the magnetic drum storage to locations s to (s + 63) in the electrostatic storage.

Miscellaneous Operations

17	0 A	Clear the A register.
18	0 U	Clear the U register.
19	Stop	Stop machine operation.

Shift Operations

20	AR(n)	Shift the contents of the A register (excepting sign digit) n places to the right. The vacated digital positions on the left take the same condition as the sign digit. The overflow to the right is dropped.
21	AL(n)	Shift the contents of the A register and the U register (excepting sign digits) n places to the left. The first overflow on the left of the A register is placed in the lowest digital position of the U register and the vacated position of the A register is made zero.

Arithmetic Operations

22	s Ah	Add the number at storage location s to the word in the A register and place the result in A.
23	-s Ah	Add negatively the number at storage location s to the word in the A register and place the result in A.
24	|s| Ah	Add the absolute value of the number at storage location s to the number in the A register and place the result in A.

Operation Number	Coding Symbol	
25	- |s| Ah	Add negatively the absolute value of the number at storage location s to the number in the A register and place the result in A.
26	m s	After clearing the A register, multiply the number at storage location s by the number in the U register and form the left-hand product in A and the right-hand product in U.
27	M s	After clearing the A register, multiply the number located at storage position s by the number in the U register and form the rounded-off product in the A register.
28	d/s	After clearing the U register, divide the number in the A register by the number located at storage position s and form the quotient in U with the remainder in A.
29	D/s	After clearing the U register, divide the number in the A register by the number located at storage position s and form the rounded-off quotient in the U register.

Read-Record Operations

30	RD (i_1, i_2, s)	Read words i_1 to i_2 inclusive from the magnetic tape of the magnetic tape reader and place them in consecutive storage locations starting at s.
31	RC s	Record the contents of storage location s on the magnetic tape recorder.

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