File

V

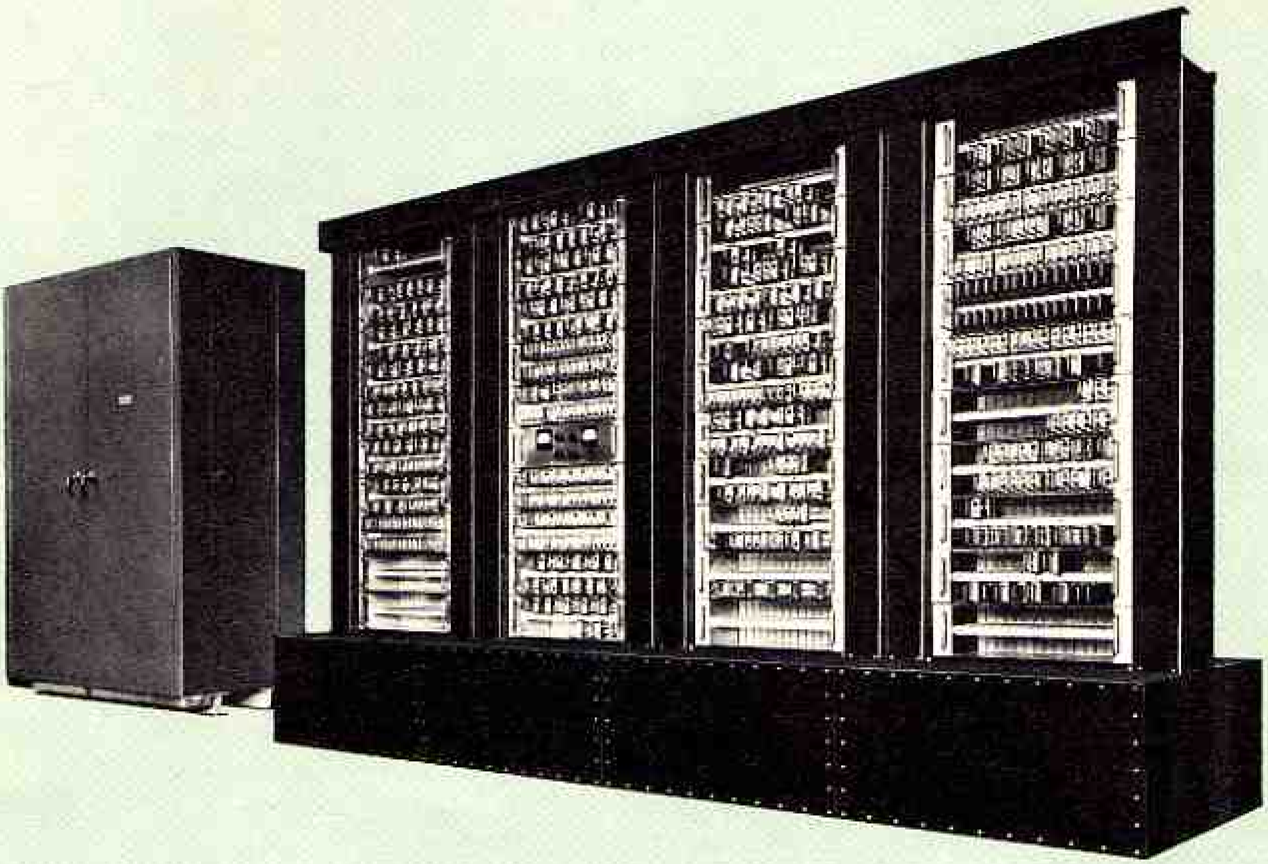
MIDAC

UNIVERSITY OF MICHIGAN
ARTES SCIENTIA VERITAS
1817

Automatic Computer

Willow Run Research Center
Engineering Research Institute
University of Michigan
UMM-101

MIDAC

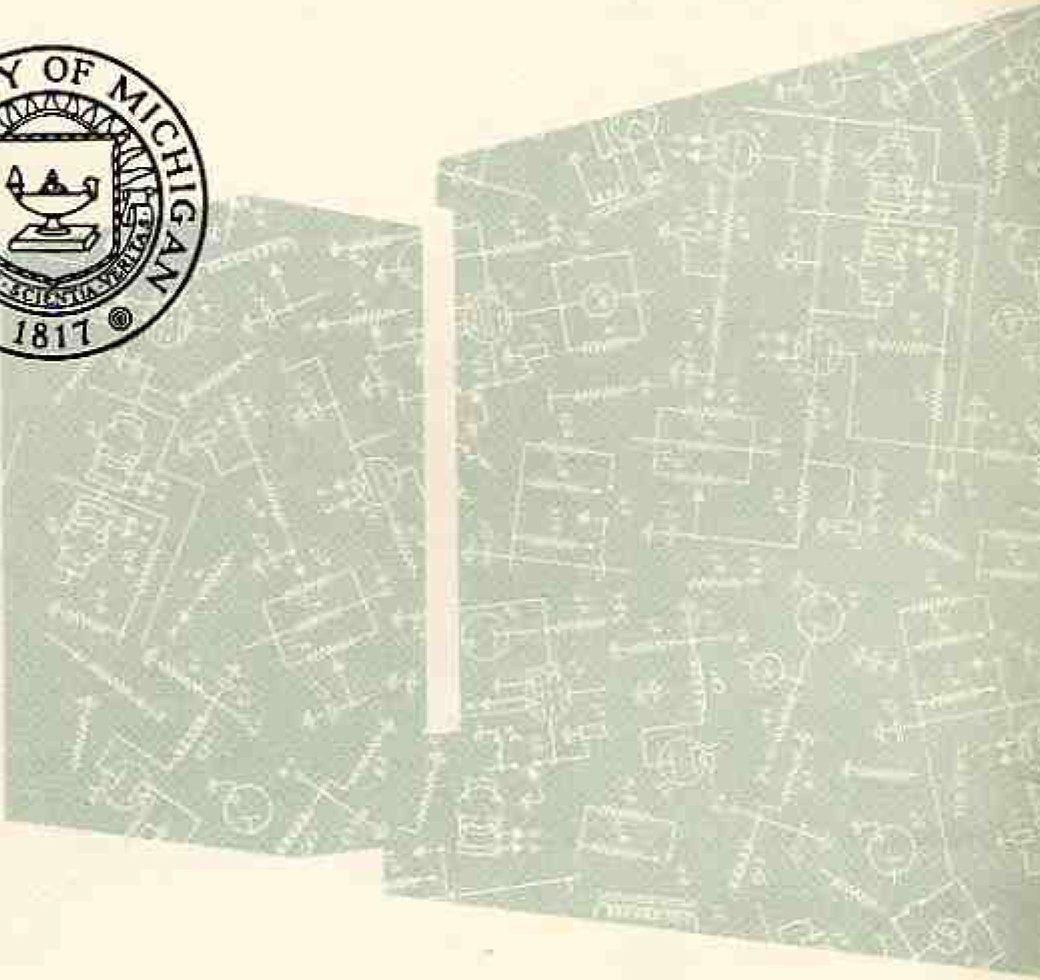


A New High-Speed Digital Computer Now at the Service of the National Defense, Science, and Industry

UNIVERSITY OF MICHIGAN

ARTES · SCIENTIA · VERITAS

1817



In February 1951, under the sponsorship of the Wright Air Development Center, United States Air Force, the Willow Run Research Center of the Engineering Research Institute, University of Michigan, undertook the construction of the MIDAC (MIchigan Digital Automatic Computer) described in this booklet. The ultimate purpose of the computer is the solution of certain complicated military problems. This purpose led to the design numbers chosen for incorporation into its construction. Happily, it has turned out that these design numbers agree with those which would be chosen for a large class of general problems which are solvable on digital computers.

The need for a machine in a relatively short time led to the adaptation of techniques already tested and tried in the SEAC developed by the National Bureau of Standards. The cooperation of the Bureau has been wholehearted, and the greatest thanks are due the members of the Bureau staff who so willingly aided in consultation during the design and construction of the machine.

It is believed that a facility of broad applicability has been added to the equipment available at the University of Michigan. The purpose of this booklet is to make available, to those unfamiliar with this machine, its characteristics and broad design principles. Any of the members of the Digital Computation Group at the Willow Run Research Center will be happy to discuss the machine and its operation in greater detail with those who so desire.

Harlan Hatcher.

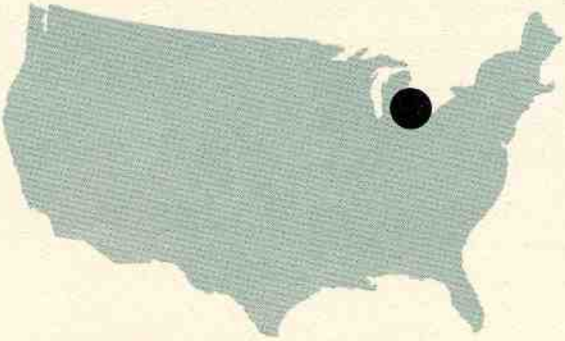
President

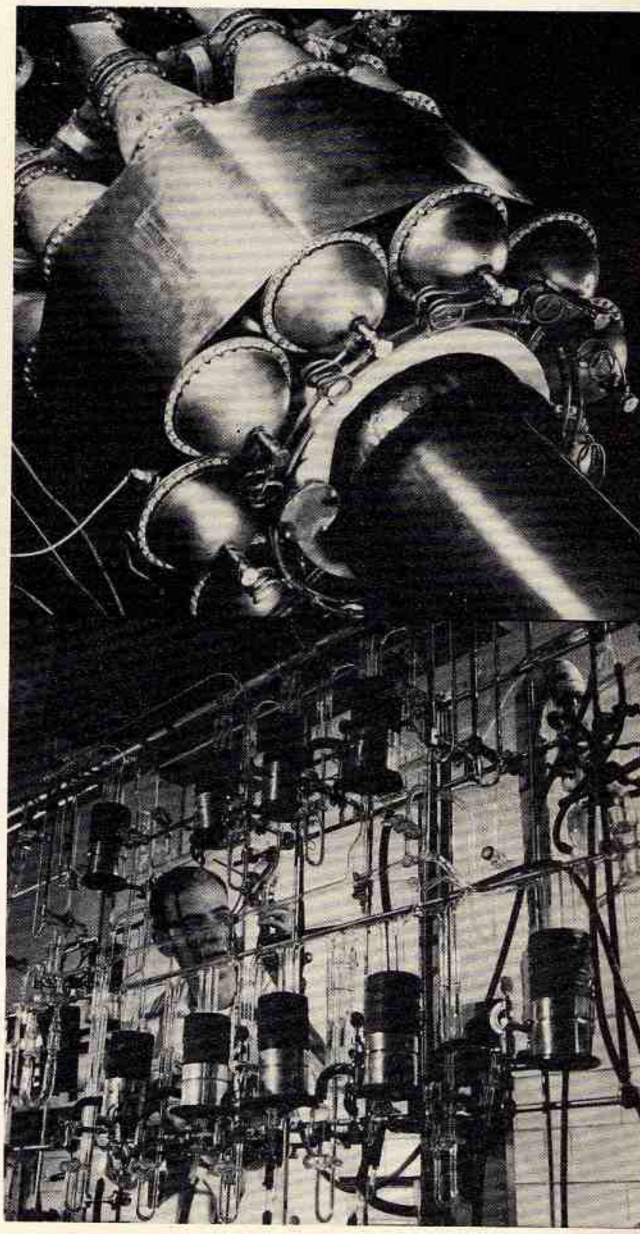
Why Build a High Speed Computer ?

The extreme complexity of modern scientific and engineering problems has developed a great need for this new type of mathematical tool. Many problems, whose solutions have previously been considered too laborious and expensive, can now be dealt with quickly and economically. With the advent of these new digital machines, it is no longer necessary to construct actual scientific or engineering systems for initial design studies. Scientists may now set up a "mathematical model" of an intricate system, follow such a system's behavior through the patterns of operation, and predict and evaluate its performance.

Electronic computers can provide models of complex physical structures ranging in size and behavior from the innermost structure of the atomic nucleus to an air traffic control system.

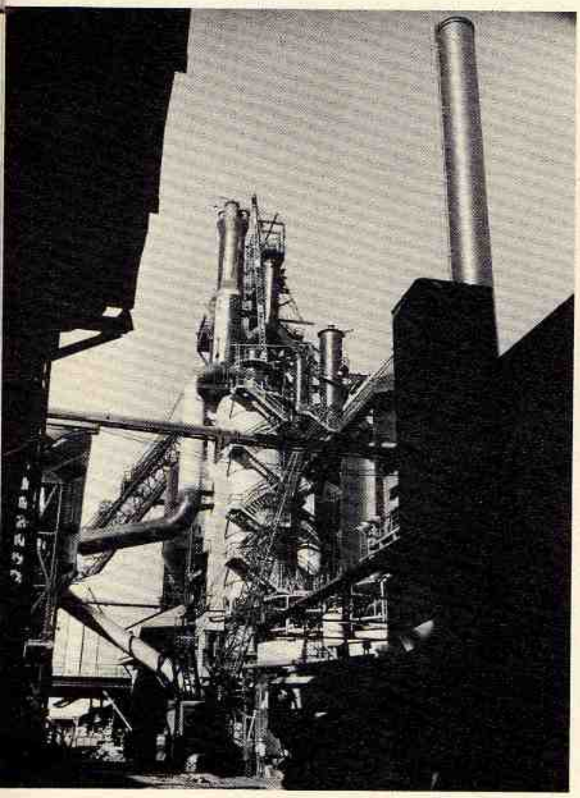
The University of *MI*chigan *D*igital *A*utomatic *C*omputer, or MIDAC, as it was named, now takes its place as one of six large-scale digital computers planned for operation in the nation's universities and technical institutions and one of about twenty throughout the country. The first such computer in the Midwest, it is located at Willow Run in the Detroit industrial area.





In the field of system simulation, electronic digital computers can simulate the dynamics of such complicated devices as guided missiles, supersonic aircraft, torpedoes, and the multiple array of new devices that have appeared during the past few years. Because MIDAC is all-electronic, it performs at very high speed as compared to mechanical or hand methods of computation. Because it is a digital computer, it can calculate and produce answers to whatever accuracy is desired.

In the general scientific and engineering fields, MIDAC will be especially useful in obtaining solutions to the following types of mathematical problems, for which numerical solutions were previously thought to be impractical:



- Solution of large sets of linear simultaneous equations and the inversion of high-order matrices.
- Determination of real or complex roots of algebraic or transcendental equations.
- Solution of high-order differential equations (linear or non-linear).
- Determination of the eigenvalues and eigenvectors of real or complex matrices and ordinary differential and partial differential operators.
- Solution of partial differential equations (linear or non-linear).
- Computation of various correlation functions and other statistics of large volumes of data.
- Solution of "minimization problems" of the calculus of variations.
- Solutions of boundary-value problems of classical and quantum physics.

MIDAC will be valuable in the solution of design problems in such fields as optical ray tracing, dynamical systems, servomechanisms, electronic networks, internal combustion engines, gas and steam turbines, and nuclear reactor design, to cite only a few of the problems already investigated on high-speed computing machinery.

In the field of process control, MIDAC will be able to provide hard-to-get answers to problems of oil-well production, refinery controls, automatic machine tool operation, and control of chemical reactions. In such varied fields as molecular structure research, design of chemical solvolysis processes, control of large-scale power systems, nuclear spectroscopy, and compilation of oil exploration tables, high-speed computers similar to MIDAC have already proved their worth.

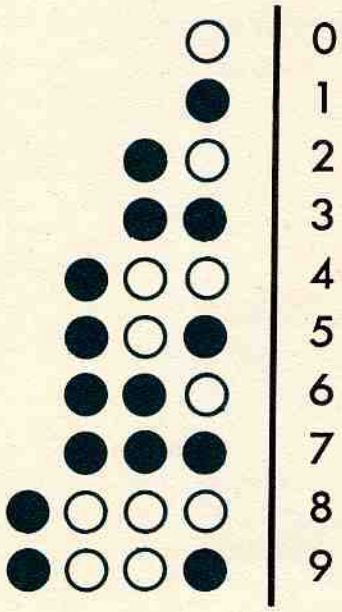
What is MIDAC?

MIDAC is a general purpose, high-speed, electronic digital computer. It operates in a serial mode, using the binary (base two) number system. The binary system uses only two digits, "0" and "1," which correspond in the machine to the absence or presence of an electronic pulse.

The MIDAC uses a group of 45 binary digits (44 digits plus a sign) as a fundamental unit of information, or "word." This "word" may convey operational instructions or numerical information to the machine. Its storage elements contain 512 words of high-speed memory, plus 6,144 words of slower-speed memory, with provision for expansion.

The same memory equipment is used to store both instructions and numbers, and the relative apportionment of memory space to each is arbitrary. Because the computer stores and uses these two types of words in identical form, instructions may easily be modified by the computer by the same logical and arithmetic operations performed on numbers and *vice versa.* This ability allows MIDAC to program some of its own computation on the basis of results of calculation within the machine, and this, with its ability to make numerical comparisons, gives the machine its important "decision" property.

Instructions are of the "three-address" type, involving two operand locations and result location.



Numbers may be given to the computer in the decimal number system; these may be converted automatically by an input translation program to the binary number system in which the computer works. Numbers may be represented in MIDAC to a precision of 44 binary digits, which is approximately equivalent to 13 decimal digits. The computer has a fixed binary point located such that the absolute value of all numbers as operated on by the computer is less than one. However, MIDAC may be programmed automatically to operate with a floating decimal point or automatic scale factor, using special instructions incorporated in the computer design to facilitate this operation.

Four main units, or blocks, make up MIDAC. These are (1) the input and output units, (2) the memory, or storage units, (3) the control units, and (4) the arithmetic units. A control console allows the operator to insert problems and monitor the performance of the machine.

Nineteen basic machine operations will be available on MIDAC:

Six of these will be the standard arithmetic operations in the machine code:

- Add (ad)
- Subtract (su)
- Multiply, Unrounded (mu)
- Multiply, Low Order (ml)
- Multiply, Rounded (mr)
- Division (dv)

Two operations will shift digits in a word to the right, or to the left, and locate the significant digits in a word:

- Shift Number (sn)
- Power Extract (px)

A particularly useful operation will allow individual digits in a word to be replaced without erasing the rest of the word. This operation will be used in modifying instructions within the machine and in withdrawing significant parts of a number for special consideration or printing:

- Extract (ex)

Three "change-of-control" operations allow the machine to make decisions based on the result of arithmetic operations, and to transfer control to automatic subroutines:

- Compare Number (cn)
- Compare Magnitude (cm)
- File (fi)

A special sequencing operation allows the computer to decide, on the basis of the relative positions of two address locations, whether to repeat a sequence of instructions just executed using new data, or to continue on into a new sequence of instructions. This operation is useful for experimental data reduction and evaluation of formulas for a large number of arguments:

- Base (ba)

Two number conversion operations allow the machine to convert numbers from outside form into the machine's own word structure and back again:

- Decimal-to-Binary Conversion (db)
- Binary-to-Decimal Conversion (bd)

Two input-output instructions allow the machine to communicate to and from primary storage with secondary storage and the outside world:

- Read In (ri)
- Read Out (ro)

Finally, two tape control instructions will allow the machine to manipulate external magnetic tape units:

- Move Tape Forward (mf)
- Move Tape Back (mb)

By use of combinations of these instructions, MIDAC will perform automatically any sequence of steps, and thus any required computation, no matter how complicated. However, MIDAC is not the "Giant Brain" of the science-fiction writers. It cannot "think" in the terms of human creativeness. It can make decisions only if told upon what basis to decide, and what to do in each case. Much work must be done by mathematicians and programmers for the machine in breaking down a problem into the simple operations of which MIDAC is capable.

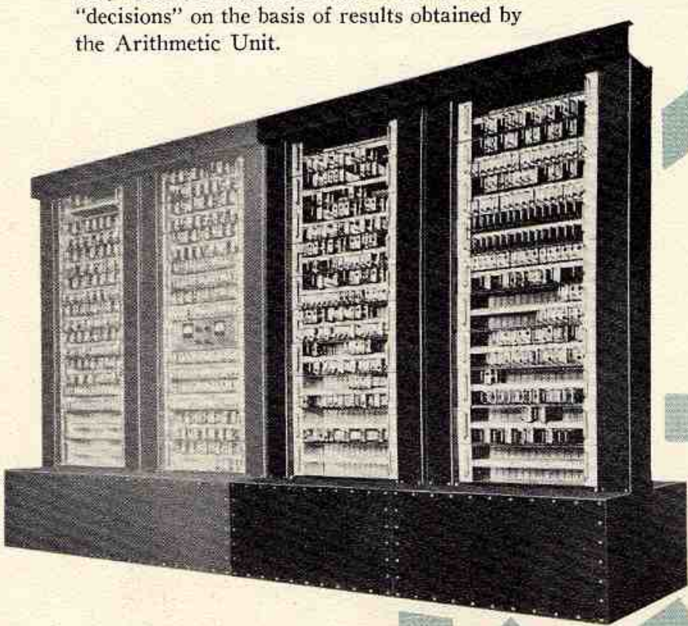
Once such a program is written and perfected, MIDAC will perform such computations automatically and rapidly. What is more important, MIDAC will repeat these computations as often as desired with different sets of numerical data, as furnished from outside.

MIDAC is a powerful tool, ready for use in solving the important problems of today, but a tool whose value will be only in proportion to the skill and imagination of those who use it.

How Does MIDAC Perforn

Control Unit

The Control Unit of the MIDAC is the central switchboard for the machine. In this element, an instruction is called in from the High-Speed (Acoustic) Memory, broken down into its component parts, and "micro-instructions" are sent out in sequence to each unit in the machine so that the overall operation may be performed. Here the machine also makes "decisions" on the basis of results obtained by the Arithmetic Unit.



Magnetic Drum Memory

The low-speed memory in the machine, presently containing over 6,000 "words" of storage, but with provision to expand to almost 25,000 "words," is a Magnetic Drum Unit. Information here is stored as magnetized regions on the surface of the cylindrical drum, and is transferred in and out by "read" and "write" magnetic heads. Data can be read out of the High-Speed Memory and stored on the Drum or read off the Drum and returned to the High-Speed Memory, when the Control Unit receives the proper instruction. Pretested subroutines and input programs can be kept permanently in this storage element.

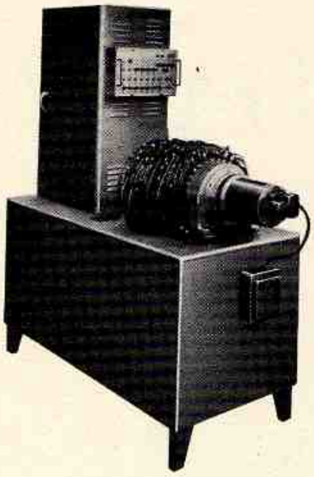
Computer Console

At the Console of the MIDAC, the machine operator starts and stops the machine and monitors the intermediate calculations. He has at his fingertips the main power switches, start-stop switches, and control switches for inserting information into the machine. Light patterns on the Console aid him in telling whether or not a problem is running satisfactorily.

High-Speed (Acoustic) Memory

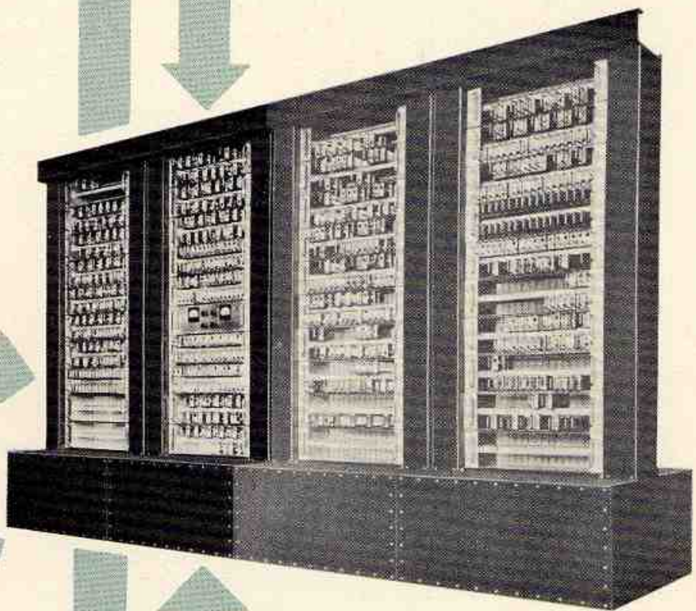
Both the instructions which control the Control Unit and the numbers on which the Arithmetic Unit operates are stored in the High-Speed (Acoustic) Memory. Here information is stored in the form of sound pulses in a liquid (mercury) medium, to be called in when the appropriate number or instruction is required. When more information than the 512 "words" available here is needed, the Control Unit can be instructed to call in more information from the Magnetic Drum Memory to replace any portion of the 512 words.

n Its Computations ?



Output Automatic Typewriter

A Flexowriter unit types out the results of the computation on paper, ready to be evaluated by the mathematician. The typewriter keys are actuated by sequences of electronic pulses, sent by the Control Unit from the High-Speed Memory.

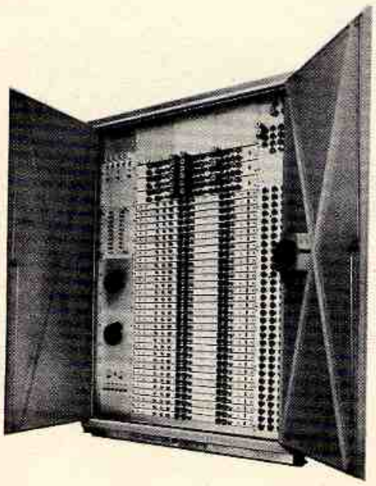


Input Photoelectric Tape Reader

The input of numbers and instructions into this machine is accomplished by a high-speed Photoelectric Paper Tape Reader, which can read in six-level punched paper tape at a speed of 200 characters per second. With such read-in speeds, computation in the machine need only wait a short time for incoming information. A light, shining through the punched holes, strikes photoelectric cells and is translated into electronic pulses, which are sent by the Control Unit to the High-Speed Memory.

Arithmetic Unit

The calculating element of the MIDAC is its Arithmetic Unit, which performs the operations of addition, subtraction, multiplication, and division on operands called in from the High-Speed (Acoustic) Memory, and then sends the result back to storage for further processing. The Arithmetic Unit also can shift numbers right and left (multiplication by powers of two) and automatically scale numbers to a conventional standard form. Multiplication can be "rounded" or "unrounded."



How Is a Problem Solved on MIDAC ?

The first step in preparing a problem for solution by MIDAC is a conference with the mathematicians of the Digital Computation Group at the Willow Run Research Center.

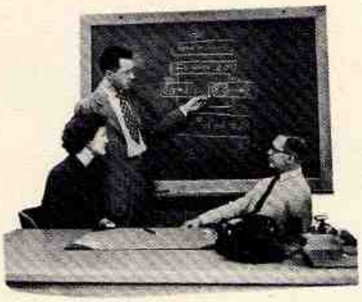
At this and succeeding discussions, the problem is analyzed carefully to determine its exact nature and the exact nature of the answer required. It is then possible to tell whether the problem is best suited to high-speed digital computation, or if it can be handled better by punch card or analog equipment.

1

If it is decided that the problem can be best solved by MIDAC, further conferences are held to determine the most efficient formulation of the mathematical equations that correspond to the problem, an estimated time of operation of the machine, and the best numerical method of solution.

Members of the Digital Computation Group and the sponsor then prepare the problem in the form of a "flow diagram."

2



From the "flow diagram," a member of the Group now "codes" the problem by breaking it down into individual steps or instructions that the machine can understand. These instructions must tell the machine exactly what it is to do and in exactly what sequence of action. There can be no ambiguity in giving MIDAC orders.

During the process of coding, the coder must include methods by which, once the problem is put on the machine, the code itself may be checked for accuracy. Parallel to each machine computation, therefore, a hand solution is often run for one case to yield "check points" to see if the machine code has been written satisfactorily.

3

Once the machine code is completed, it is sent to the Tape Room, with a request that it be typed in one of several standard MIDAC input forms. A trained typist then performs the actual translation from the code on paper into a binary form by striking a succession of keys on an automatic typewriter.

At the same time that the code is typed onto paper, a paper tape is punched out by the typewriter. The tape is then duplicated, the typewritten copy checked for errors, and both the "master" and "copy" tapes stored for further use, along with the original program which was turned in by the coder. Checks are also made for errors that might occur in duplication.

4

5

Meanwhile, the estimated amount of computer operating time for the problem has been scheduled. The programmer has presented a request to the MIDAC operator to run his tape, or tapes, in a specified order into the MIDAC High-Speed Photoelectric Paper Tape Input Reader. The operator reads each tape, using a standard read-in system, in order to eliminate waste time on the machine.

During read-in, a standard input translation program performs a translation of the coded tape, automatically, inserting subroutines stored on the drum into the High-Speed Acoustic Memory. The translation is from the outside standard form, used for ease in coding, into the binary form used in the machine. At the end of the translation, the machine automatically starts calculating at the beginning of the problem.

The MIDAC then performs the actual solution of the problem. If a mistake occurs in the programming, or in performance of the problem, automatic or pre-coded checks notify the operator by means of lights or the supervisory printer.

6

When the results of the computation become available, MIDAC types them out by means of the automatic typewriter and standard print routines. When a problem is completed, MIDAC, having previously been instructed to do so, stops and waits for the operator to insert the tape for the next problem.

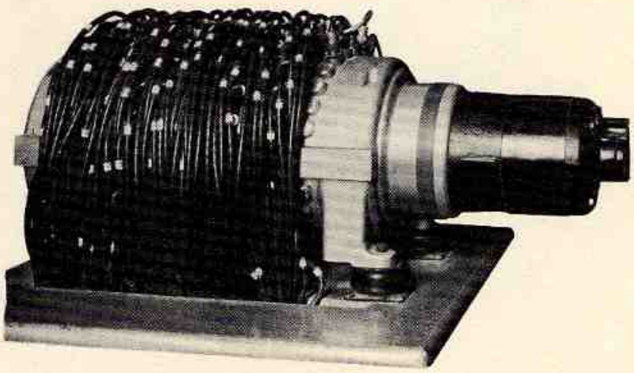
If the program does not run satisfactorily the first time, the operator makes use of various "utility programs" stored on the magnetic drum, to give the programmer information explaining the failure. Thus a "post mortem" or "Automonitor" (error diagnosis) program will be called in by the operator by insertion of an instruction through the supervisory printer, and will cause MIDAC to type out automatically the required information.

How Does MIDAC Differ from Previous Computers ?

1 It's Large Drum Storage Provides Easy Use of Subroutines

Subroutines, or pre-coded, pre-tested program blocks, have been found to be extremely important in speeding the job of giving a computing machine instructions in its own language. Most previous computers have failed to use subroutines, or if they have used them, were forced to store their subroutines outside of the machine on paper tape, punched cards, or other media.

MIDAC, on the other hand, with its present 6,144 words of drum storage, and its projected far greater amount, can keep most of its pre-tested subroutines within its own storage on its magnetic drum. Automatic call-in programs can be used to operate these subroutines completely automatically. This saves programming time, and decreases the cost of putting a problem on the machine—a cost which has run very high on other computers.



2 Built-In Relative Addresses Make Subroutine Read-In Automatic

Along with the storage of subroutines on the drum, MIDAC possesses a "relative addressing" scheme which allows subroutines to be coded once, independent of any specified position in the memory, and after storage on the drum to be called in to any acoustic memory position.

The relative address system automatically assigns proper acoustic memory addresses within the body of the subroutine, and eliminates the need of a programmer's determining the absolute addresses of the final subroutine by hand.

❸ A Special "Base" Operation Aids in Rapid Data Processing

All recent automatic computers have been able to modify their own stored instruction program on the basis of previous results. Such cyclic program sequences, or "iteration loops", are helpful in handling matrix manipulations, in processing large amounts of data, and in handling any large problems of a cyclic nature.

MIDAC has been built with a special "base" operation designed just for such iteration loops. This instruction performs an operation accomplished in other computers only by a combination of instructions. Its special counting features, along with the relative address features, combine to save both storage and speed of operation in large problems.

❹ A Built-In Instruction Provides Speedy Binary-Decimal Conversion

Like most recent electronic computers, MIDAC is a binary (base two) machine. However, special instructions in the MIDAC speed up the conversion of numbers from external decimal notation to the machine's internal binary system and *vice versa*.

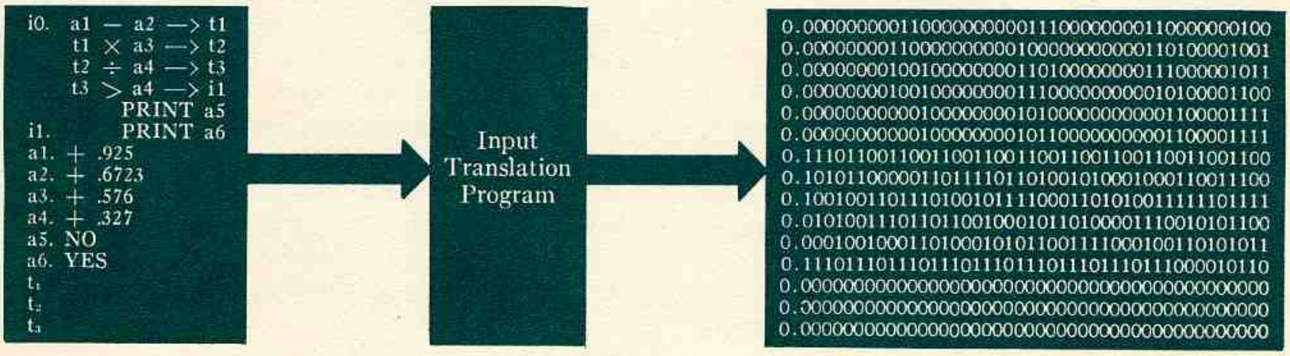
Thus, two conversion instructions, decimal-to-binary and binary-to-decimal, aid the MIDAC programmer in translating his numbers from one form to another. This saves both machine and programming time.

❺ An "Input Conversion-Translation Program" Speeds Programming

Coding of problems for MIDAC, unlike similar tasks on most other machines, is greatly aided by an "input conversion-translation program" which performs the complete task of translating the code for MIDAC problems from the external more familiar form into the binary language of the machine.

As an example, if the machine is to be asked the simple question below, the coder writes his instructions to the machine in the simplified form at the left, rather than the more unfamiliar form at the right, and the "input conversion-translation program" performs the complete translation for him.

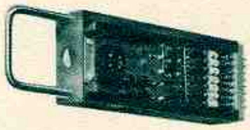
$$\text{Is } \frac{(+925\ -\ .6723)\ (+.576)}{+.327} \quad > \quad +.327?$$

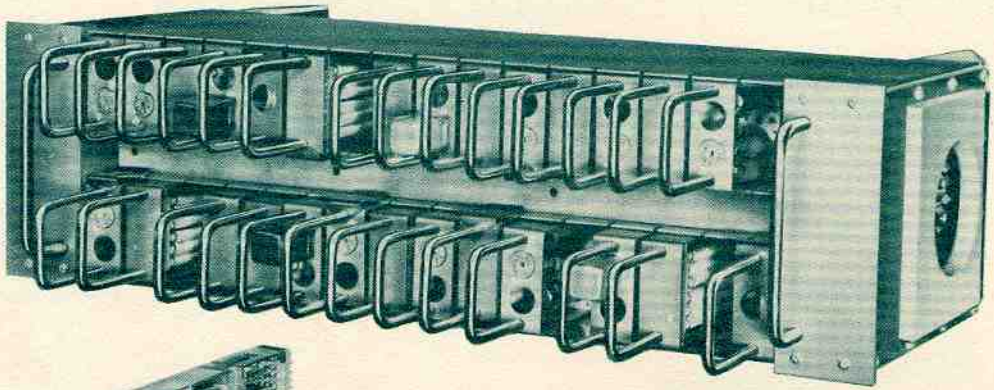


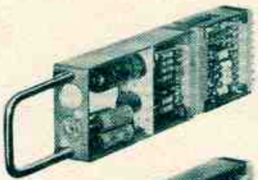
External Program
(Decimal-Algebraic Code)

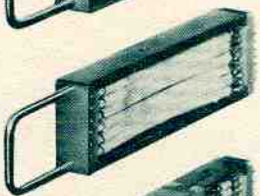
Internal Machine Program
(Binary Code)

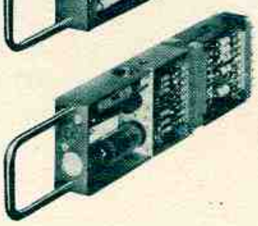
6 Packaged Units Provide Ease of Maintenance









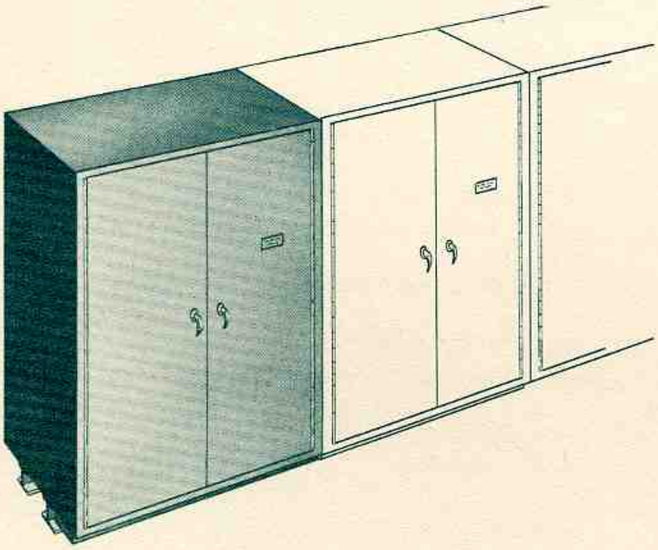


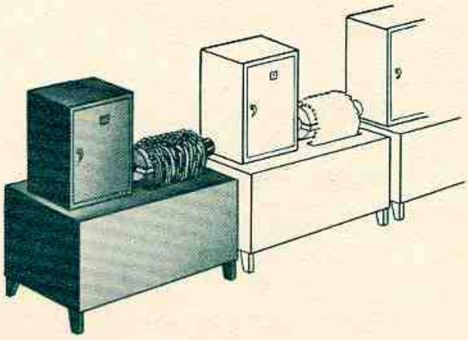
Although "packaged units" have been used to some extent on other computers, MIDAC has carried this efficient "building-block" type of construction to its logical conclusion. The machine (except for the storage elements) is composed of only six different types of individual packages. Any unit can be replaced by simply pulling it out and plugging in a duplicate.

These packages are the result of circuit developments at the National Bureau of Standards in Washington, D. C., at the Air Force Missile Test Center, Patrick Air Force Base, Florida, and at the University of Michigan. Their use as the basic elements of a computer provides ease of maintenance, convenience of cooling, rapid repair of machine failures when they occur, and makes possible rapid mass production of computers when required.

Each package contains no more than one tube and is a logical element in itself. There are six basic building block packages, three of which are made up of combinations of "and" and "or" gates. The other three are termination packages, relay driver packages for use with the magnetic drum, and delay line packages. Only one type of tube, one type of diode, and eight sizes of resistors are required with these units. Their use guarantees flexibility in making future engineering changes and additions that may be needed in MIDAC.

❼ "Room to Grow" Allows Future Increases in Memory Size without Internal Circuitry Changes





When problems increase in size beyond the present capacity of the machine, MIDAC does not become obsolescent. Instead, a simple addition of duplicate memory equipment, without changing any of the internal control circuits, will allow the machine to meet such new challenges.

At present, MIDAC's acoustic memory contains 512 words of storage; however, its control circuits were planned to provide for expansion to 1,024 words.

Similarly, its magnetic drum storage at present is 6,144 words, but control circuits are built in so that the machine can later be expanded to 24,576 words of magnetic drum storage, without redesigning any of the control mechanism. Provisions are also available for addition of magnetic tape units without redesign of the basic logic.

MIDAC is now in operation at the University of Michigan's Willow Run Research Center at Willow Run Airport.

285

MIDAC Specifications

Type of Computer	General purpose, high-speed
Electronic Design	Digital, with crystal diode gating structure. Based originally on the SEAC logic and circuitry
Number System	Binary
Storage Register Length	45 Binary digits, equivalent to about 13 decimal digits
Arithmetic Structure	Fixed binary point, with special instructions built in for aid in double precision and floating-point coding
Method of Computation	Serial digit transmission, storage, and computation
Primary Storage	Initially 512 registers of acoustic mercury delay line storage; later 1,024 registers
Secondary Storage	Initially 6,144 registers of magnetic drum storage; later 24,576 registers
Auxiliary Storage	Magnetic tape units to be added
Storage Access Time . . . . (Time to find storage location)	From 0 to 384 microseconds, dependent on word required, for primary storage; from 0 to 16 milliseconds, dependent on word required, for secondary storage
Computation Time . . . . (Includes all necessary access times to Acoustic Memory)	Addition—192 to 1,536 microseconds Subtraction—192 to 1,536 microseconds Multiplication—2,304 to 3,168 microseconds Division—2,304 to 3,168 microseconds Comparisons—192 to 1,200 microseconds Number conversions—768 to 1,776 microseconds
Input	High-speed photoelectric paper tape reader, to be supplemented by magnetic tape equipment
Output	Automatic electric typewriter, to be supplemented by curve-plotting oscilloscopic output and high-speed mechanical or photographic printer

Litho in U.S.A.