

GENERATIONS:

- m = manual
- me = mechanical
- em = electromechanical

- 1 = electronic—vacuum tube
- 2 = transistor
- 3 = integrated circuit
- 4 = large scale integrated circuit

A COMPANION TO THE PIONEER COMPUTER TIMELINE

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The Computer Museum Report is published quarterly by The Computer Museum, One Iron Way, Marlboro, MA 01752. Annual subscription is part of the membership of the Museum (\$25 per year for individuals and nonprofit organizations and \$125 for corporations).

The purpose is to report on the programs and exhibitions of the Museum. The contents of The Computer Museum Report may not be reproduced without written consent.

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INTRODUCTION

This booklet is meant to be an exemplary companion: informative, attractive and user-friendly. People who visit the Timeline, a permanent gallery devoted to the first, one-of-a-kind computers, can use this companion as a supplement to the exhibit, and those who read it as the Winter 82/83 issue of the Report can gain a sense of the Pioneer Computer Timeline.

The concept of developing a permanent gallery devoted to the first computers grew out of the Pioneer Computer lecture series initiated by the curator, Gordon Bell. The lecture series, archived on videotape, was led off on September 23rd, 1979, by Maurice Wilkes on the EDSAC. Then George Stibitz not only talked about the Bell Telephone Relay Computers but reproduced his "Model K" adder for the Museum. John Vincent Atanasoff, the fourth speaker, loaned the breadboard Atanasoff-Berry Computer for display. With these pieces, as well as the major Whirlwind artifacts and the information gathered at the lectures, the idea of assembling them into an integrated exhibit emerged.

The exhibit itself, 100 feet long on the balcony of the Museum's lecture hall, was designed and mounted by Jamie Parker and lighting consultant Christopher Ripman. Their concerns were attractiveness and legibility—both for the person in the lecture hall and the studious visitor—as well as flexibility for growth and change.

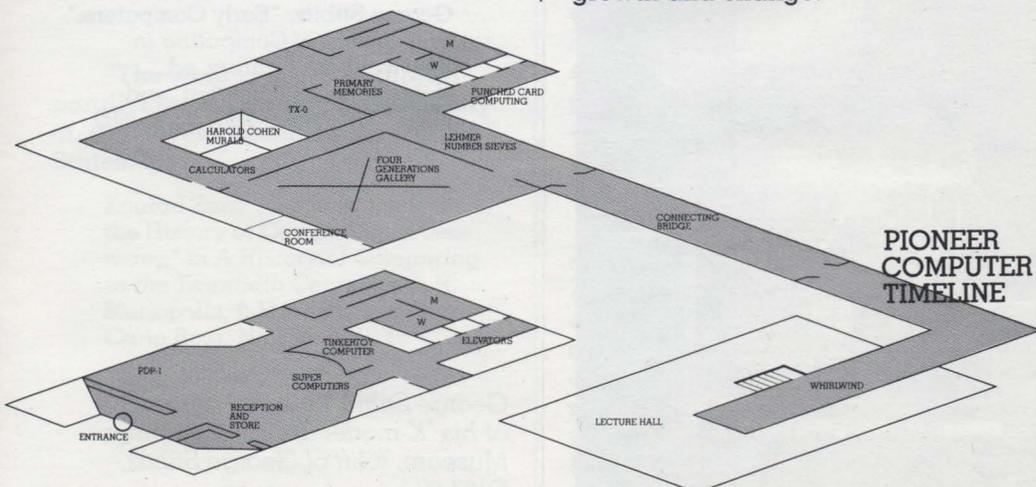
Beth Parkhurst carried out the research and compiled the text for both the exhibit and its companion. The Timeline has the specifications spelled out for each machine, an overall view of the machine, and basic descriptive materials. For the companion, Beth chose quotations that would begin to approximate the sentiments of F. C. Williams: "It is fairly easy by reference to such records as survive to describe what had been achieved twenty-five years ago. What is difficult is to recreate the environment of uncertainty and excitement in which those achievements occurred." (F. C. Williams, *The Radio and Electronic Engineer*, 45, 1975.)

Coordinating the companion, my main concern was to provide a picture indicative of the Museum's exhibit. In some cases, I chose photographs of the artifacts on display at the Museum, in others "period" drawings, and in still others the portraits of the machine itself. And I also insisted on the reference page that would indicate where primary materials existed on these pioneer computers. While many of the original sites of the machines maintain an exhibit and archives, the Computer Museum is the only place that has an integrated exhibit of the Pioneer Computers.

Gordon Bell insisted that this companion, as well as the timeline, put the pioneer computers in their historic perspective, and made the comparative table that appears on page 14 and the graph on the cover. In compiling the data, we've selected from sometimes conflicting information and will keep a running corrected table.

The Timeline is not yet complete. The next Pioneer Computer Lecture, by Captain Grace Hopper on the Harvard Mark I is scheduled for April 14. At some time, we will integrate video-taped material into the exhibit; but for now have settled on keeping it available in the archive. Your suggestions, corrections, and donations relevant to this exhibit, the lecture series and the archive are encouraged.

Gwen Bell
Director



Bell Telephone Laboratories Model I Complex Calculator

George Stibitz worked at Bell Labs as a mathematician in the 1930s. In his spare time, he experimented with using telephone relays for electro-mechanical calculation.

"The original notions that led to the series of relay computers had nothing to do with usefulness. I just wondered whether it would be possible to make such simple things as relays do complicated calculations . . .

"I was then a 'mathematical engineer' at the Bell Telephone Labs, and as such I was asked to look into the magnetic circuits of the telephone relay. As you know, a relay is just an electrically-operated switch that opens and closes one or a dozen electrical circuits.

"While looking at the relay's magnetic circuit I naturally noted the piles of contacts that could be closed or opened when the relay operated. I knew that these contacts could be connected in large and complicated meshes, and when so connected they could do very complicated jobs. So, I liberated a pair of relays from the Labs' junk pile and tried out a few circuits.

"Years before in a freshman

math course I had learned a little about the binary notation for representing numbers. That notation has digits with only two values, such as zero and one, much as the relay has only two 'values': open and closed.

"It occurred to me that perhaps the two positions of a relay could be used to represent the two values of a binary digit. Then perhaps circuits through the contacts of several relays might represent the two values of a binary digit. I soon found out that this was true—two relays could be wired together to add two binary digits.

"I built an adder of the two relays I had borrowed, a couple of dry cells, two flashlight bulbs, and two strips of metal for keys. My wife named it the K-model, after our kitchen table.

"When I took the K-model to the Labs to show the boys, we speculated on the possibility of building a full-size calculator out of relays. Shortly thereafter the relay computer turned serious."

George R. Stibitz, "Early Computers and Their Uses," presented at Computing and Chili-eating Society, 1981

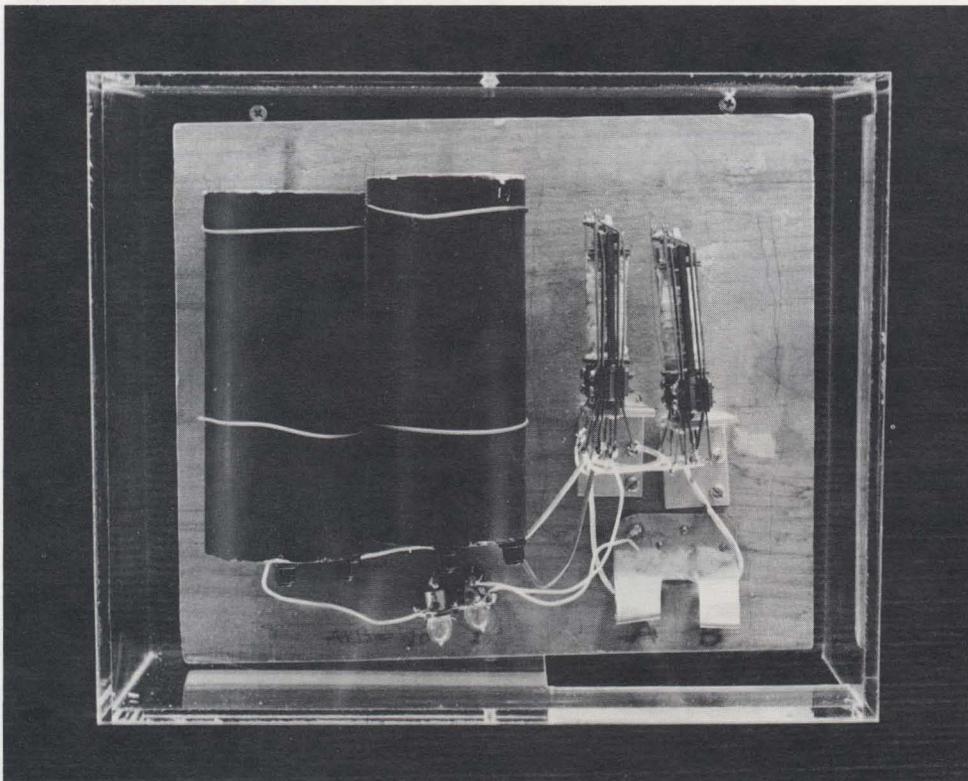
Around that time, the head of the mathematical engineering group came to Stibitz with a problem. Recent developments in filter and transmission line theory were overloading the desk calculator team with complex number work. Could a large-scale relay calculator handle the work?

Bell Labs made Stibitz's relay project official with a budget and circuit designer. The Model I, first in a series of Bell Labs relay calculators and computers, was finished in 1939. Technically, the Model I was not a true computer because it was not controlled by a program. Rather, it was operated directly through a teletype. Although it lacked the speed of the electronic computers that were to appear a few years later, its relays were far less liable to failure than vacuum tubes.

The Bell Labs Model I was the first demonstration of a large-scale digital machine for complex calculation.

"In September 1940, after several months of routine use at the Laboratories, the computer was demonstrated at a meeting of the American Mathematical Society held at Dartmouth College, in Hanover, New Hampshire . . . I gave a short paper on the use and design of the computer after which those attending were invited to transmit problems from a Teletype in McNutt Hall to the computer in New York. Answers returned over the same telegraph connection and were printed out on the Teletype."

George Stibitz, "Early Computers," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980



George Stibitz built this replica of his "K-model" for the Computer Museum. (Gift of George Stibitz, D127.80.)

Zuse Z1, Z3

As a civil engineering student in 1930s Berlin, and later as an aircraft engineer, Konrad Zuse had to spend his time performing "big and awful" calculations. Theoretical advances that would change civil engineering from "cut-and-try" to science were starting to appear, but were not being applied because of the volume of computation required in the new approach. Zuse decided to build calculating machines to solve these problems automatically.



Konrad Zuse examines a program tape.

"The work proceeded almost parallel to, but quite independently of, the developments in the United States."

Konrad Zuse, "Some Remarks on the History of Computing in Germany," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980.

"Zuse describes . . . how his work was carried out in ignorance of that of his predecessors, or even the contemporary work by Dirks in Germany on magnetic storage systems . . . During the war the various American computer projects were of course subject to strict security measures; it was only a photograph that German Military Intelligence had obtained of the Harvard Mark I which eventually alerted Zuse to the fact that the Americans had developed some sort of large scale tape-controlled computer. Nothing however prepared him for the post-war release of information about ENIAC, which with its 19,000 valves far surpassed anything that he or Schreyer had ever contemplated attempting to construct."

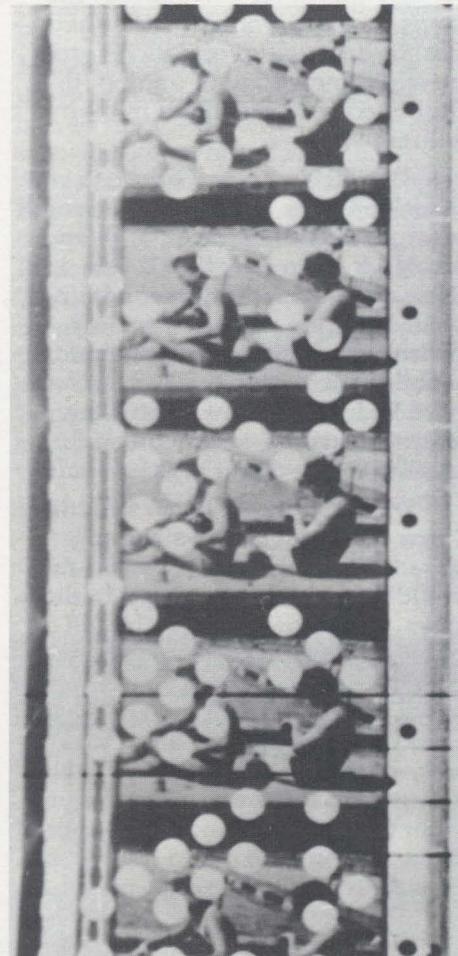
Brian Randell, *The Origins of Digital Computers*, 3rd ed., Berlin, 1982.

The designs Zuse began in 1934 led to a series of machines that included the first program-controlled computer. He built an experimental mechanical computer, the Z1, in the family living room. The Z1, completed in 1938, was followed in 1940 by the Z2, a prototype electro-mechanical computer built with second-hand telephone relays.

The Z3, a full-scale relay computer, was running in 1941. For the first time, the German government aided with funding. This machine had most of the basic features associated with a conventional computer, including memory and a form of program control. Like Stibitz's electro-mechanical calculator, the Z3 was several orders of magnitude slower than the first electronic computers. Its program was external, coded on punched film. Two special-purpose models, the S1 and S2, were used in aircraft design.

These first machines were destroyed in the war. At the war's end, Zuse learned about the American computer ENIAC, and an American observer published a description of a preliminary version of Zuse's next relay machine, the Z4. It was not until the 1960s that an English-language account of Zuse's first machines appeared.

Programs were punched on recycled motion picture film.



ABC Atanasoff Berry Computer

Beginning in 1935, John Vincent Atanasoff, a physics professor at Iowa State College, pioneered digital electronics for calculating. His students were working with linear partial differential equations, and he experimented with analog, then digital calculators to aid in their solution.

"I tried again and again to sort these concepts out. Nothing seemed to work. After months of work and study I went to the office again one evening but it looked as if nothing would happen. I was extremely distraught. Then I got in my automobile and started to drive. I drove hard so I would have to give my attention to driving and I wouldn't have to worry about my problems.

"When I finally came to earth I was crossing the Mississippi River, 189 miles from my desk. You couldn't get a drink in Iowa in those days, but I was crossing into Illinois. I looked ahead and there was a light and, of course, it was a tavern. I went in and got a drink, and then I noticed that my mind was very clear and sharp. I knew what I wanted to think about and I went right to work on it and worked for 3 hours, and then got in my car and drove slowly back to Ames.

"I had made four decisions in that evening at the Illinois road

Atanasoff built this simple model of the ABC to demonstrate his concepts of digital computation. The number stored in one of the capacitor drums is added to or subtracted from the number stored in the other drum.
(On loan from J. V. Atanasoff, X12.80.)



house: use electricity and electronics—that meant vacuum tubes in those days; use base 2, in spite of custom, for economy; use condensers, but regenerate to avoid lapses; compute by direct action, not by enumeration."

John Vincent Atanasoff, Pioneer Computer Lecture, at The Computer Museum, November 11, 1980



Professor Atanasoff lecturing to students at Iowa State University in the late 1930s.

Atanasoff and graduate student Clifford Berry built a prototype ABC (Atanasoff-Berry Computer) in 1939, and a full-scale model in 1942. Like the Bell Labs Model I, the ABC was not a computer in the modern sense, since it lacked program control and was not general purpose.

The ABC was the first of several proposals to use electronics for calculation or logic in the decade after Atanasoff began investigations in 1935. Other projects and proposals included those of Bush and Crawford both at M.I.T.; Zuse and Schreier in Berlin; the British foreign office; Rajchman at R.C.A. The makers of the ENIAC, the first electronic computer, were familiar with Atanasoff's and Rajchman's work. The degree to which the ABC influenced the ENIAC design is still being debated by participants and historians.



IBM ASCC (Harvard Mark I)

The IBM ASCC (Automatic Sequence Controlled Calculator), also known as the Harvard Mark I, began in the mind of Harvard instructor Howard Aiken, and was realized by a team representing Harvard, the U.S. Navy, and IBM.

"The desire to economize time and mental effort in arithmetical computation, and to eliminate human liability to error, is probably as old as the science of arithmetic itself . . .

"The intensive development of mathematical and physical sciences in recent years has included the definition of many new and useful functions, nearly all of which are defined by infinite series or other infinite processes. Most of these are tabulated inadequately and their application to scientific problems is retarded thereby.

"The increased accuracy of physical measurement has made necessary more accurate computation. Many of the most recent scientific developments are based on nonlinear effects. All too often the differential equations designed to represent these physical phenomena may be solved only by numerical integration. This method involves an enormous amount of computational labor. Many of the computational difficulties with which the physical and mathematical sciences are faced can be removed by the use of suitable automatic calculating machinery.

"The development of numerical analysis, including the techniques of numerical differentiation and integration, and methods for solving ordinary and partial differential equations have reduced, in effect, the processes of mathematical analysis to selected sequences of the five fundamental operations of arithmetic: addition, subtraction, multiplication, division, and reference to tables of previously computed results. The automatic sequence controlled calculator was designed to carry out any selected sequence of these operations under completely automatic control."

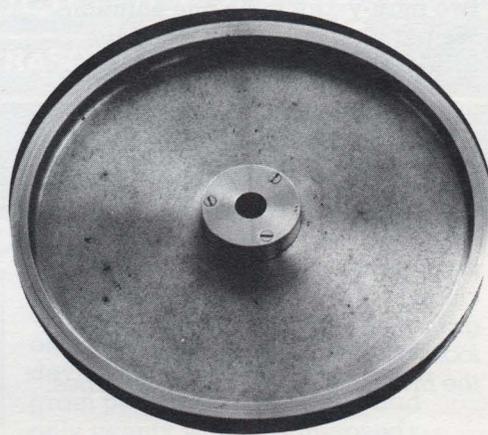
Howard Aiken and Grace Hopper
1946 *Electrical Engineering*

Inspired by Charles Babbage's nineteenth-century "Analytical Engine," the Harvard Mark I was mostly mechanical. Counter wheels were electro-mechanical, and connections between units were electrical. An external program punched on tape controlled operation; conditional branches were not possible when the machine was first in operation. The machine was largely built of standard IBM equipment. It was completed at IBM in 1943, and moved to Harvard in 1944.

The Harvard Mark I's contribution was not in its technology—the electronic ENIAC, which would surpass the Harvard Mark I's speed by several orders of magnitude, was under construction when the Mark I was being dedicated.

"If you hated Hitler enough, you would fight on against fearful odds. You considered not just the small probability of success, but the large payoff if you were successful."

I. J. Good, "Pioneering Work on Computers at Bletchley," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980.



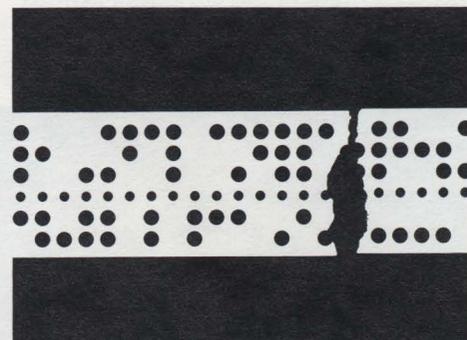
Pulley from a Colossus tape drive. (Gift of Toby Harper, X49.82.)

This spirit motivated the British Foreign Office's cryptanalytic effort at Bletchley Park. German forces relied on variants of the ENIGMA machine for enciphering in World War II. The simplest version of the ENIGMA had 9×10^{20} initial settings, so breaking the cipher was an awesomely complex process. The British built a series of machines to decipher intercepted German messages. The culmination of the series was the Colossus line, electronic machines with many of the features of the computer, including electronic circuits for Boolean logic, counting, and binary arithmetic; automatic operation, with logic functions set with plugs and switches, or conditionally selected by electro-mechanical relays; and electronic registers changeable by an automatically controlled sequence of operations.

The first official release of information on the Colossus was not until 1975. Because of this secrecy, the Colossus did not directly influence the computer projects which flourished in England and the

United States after the war. The Bletchley Park effort, however, did turn out a number of scientists experienced in electronics and logic. F. C. Williams, head of the postwar Manchester University computer project, remembered help he received from two Bletchley alumni who were also familiar with American computer projects: **"Tom Kilburn and I knew nothing about computers, but a lot about circuits. Professor Newman and Mr. A. M. Turing in the Mathematics Department knew a lot about computers and substantially nothing about electronics. They took us by the hand and explained how numbers could live in houses with addresses and how if they did they could be kept track of during a calculation."**

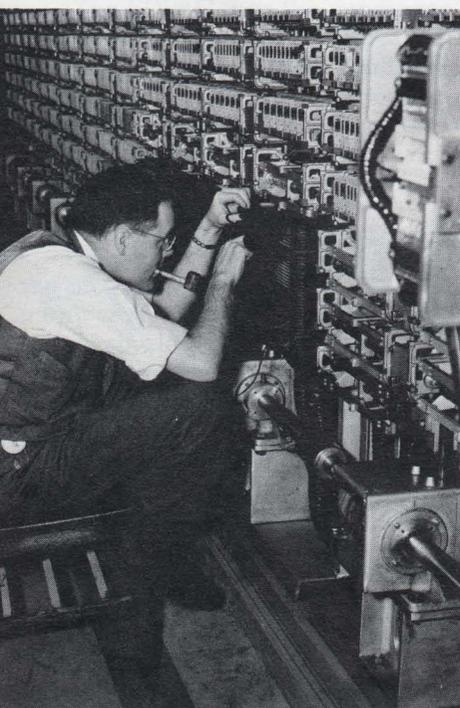
F. C. Williams, "Early Computers at Manchester University," *Radio and Electronic Engineer*, 1975



Intercepted German messages were punched on paper tape and read into the Colossus photoelectrically.

"The value of the work I am sure to engineers like myself and possibly to mathematicians like Alan Turing, was that we acquired a new understanding of and familiarity with logical switching and processing because of the enhanced possibilities brought about by electronic technologies which we ourselves developed. Thus when stored program computers became known to us we were able to go right ahead with their development."

T. H. Flowers, letter to Brian Randell, February 15, 1972; quoted in B. Randell, "The Colossus," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980.



Re-assembling the machine at Harvard, March 10, 1944.

"It is important because it was the first large scale digital calculator ever built and also because it stimulated the imagination and interest of the world and thus gave impetus to the desire for more and better computing machines."

G. Truman Hunter, "Modern Computing Machines," *Journal of the Franklin Institute*, 1952.

Each of these earlier machines had some of the features of the electronic computer. In the ENIAC, these features—electronic, high-speed operation, general-purpose capability, and program control—were combined. It is usually regarded as the first true electronic computer. The major difference between the ENIAC and later computers was that it was programmed by plugs and switches, rather than running a stored program.

The ENIAC, funded by the Army Ballistics Research Laboratory at the University of Pennsylvania's Moore School, used electronics on an unprecedented scale. Its 18,000 vacuum tubes belied the criticism that, given the failure rate of vacuum tubes, one or more tubes would fail before a computation was completed. The success of electronics for large-scale computation inspired a number of postwar computer projects.

The ENIAC was moved to the Army's Aberdeen Proving Ground after a year of operation at the Moore School. R. F. Clippinger, a mathematician who devised some of the first applications at Aberdeen, recalled:

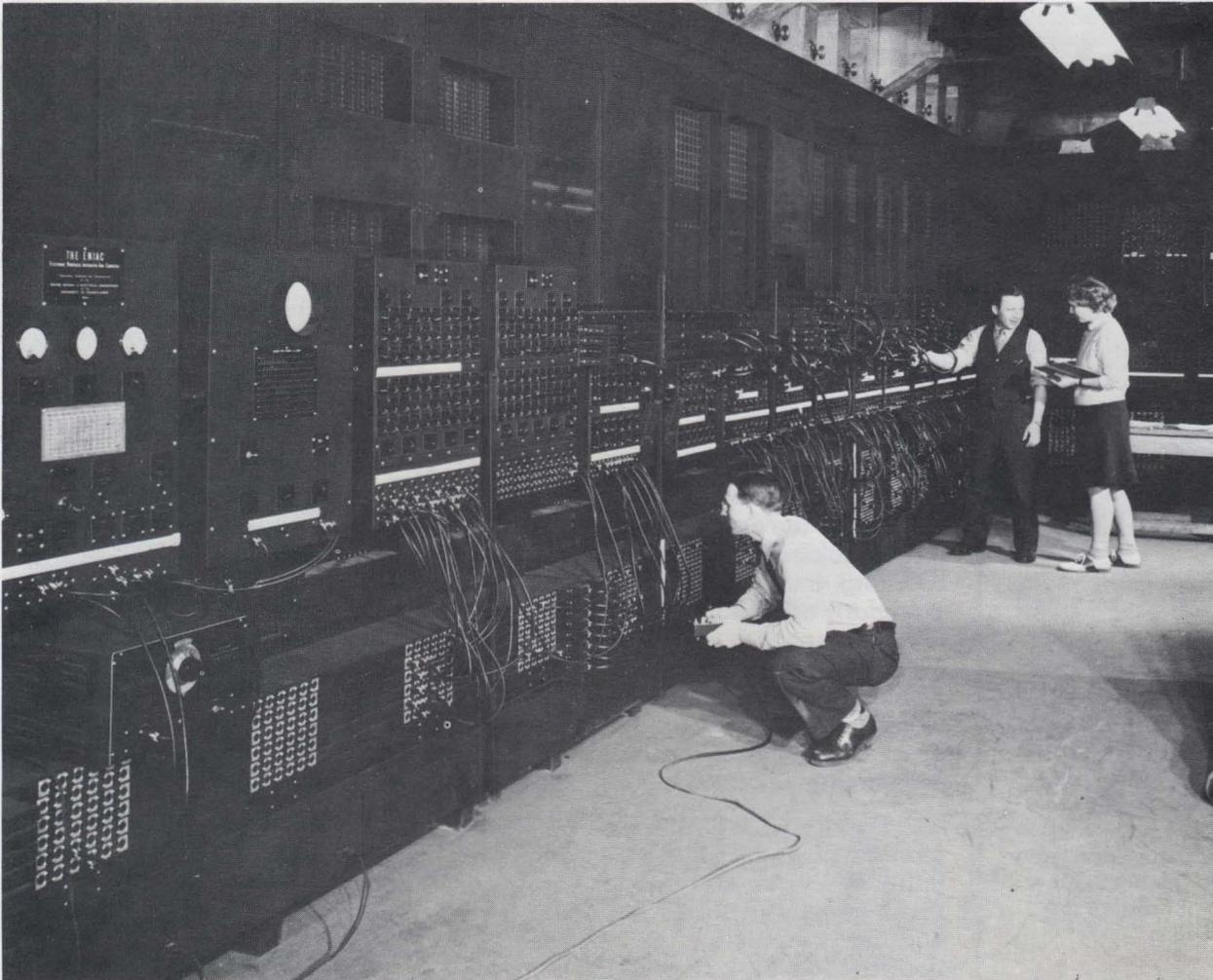
"I had a couple of girls with desk calculators working out the test case that I would use to find out if I was getting the right answers from the ENIAC. It took them two man-years to do one solution. We put it on the ENIAC, and the ENIAC ran off a case very hour . . .

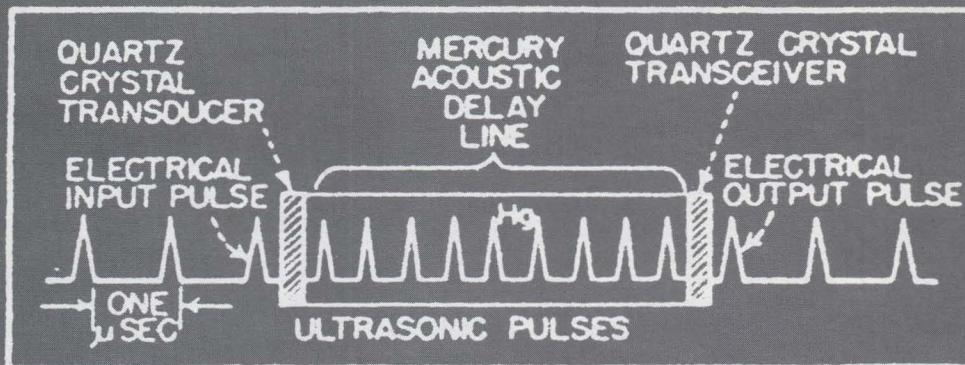
"You have to realize that the Aberdeen Proving Ground was the

The ENIAC team, headed by J. Presper Eckert and John Mauchly, included a dozen engineers and programmers. Designer Arthur Burks looks on as a program is set up on the ENIAC with plugs and switches.

cradle of a whole lot of computers: the EDVAC, ORDVAC, and a bunch of others. But even after they were delivered, the ENIAC continued to work for about ten years. There was a period when the ENIAC was the only computer working. A lot of others were on the drawing boards or in the mill being engineered, but not working."

R. F. Clippinger, gallery talk at the Computer Museum, September 26, 1982





The EDVAC was the successor to the ENIAC. While the ENIAC was being built, its designers realized the potential of the stored program. They began designing a new computer, and were soon joined by distinguished mathematician John von Neumann.

The question "Who invented the program?" has been answered many ways. It cannot be attributed to any single person, but seems to have arisen in the course of conversations among ENIAC project members; other researchers may also have independently conceived the idea. Arthur Burks, who worked on the ENIAC, beginning of the EDSAC, and with John von Neumann on the IAS computer, made this assessment of the process of making the stored program practical.

"There were two main steps. Pres and John (Eckert and Mauchly, of ENIAC) invented the circulating mercury delay line store, with enough capacity to store program information as well as data. Von Neumann created the first modern order code and worked out the logical design of an electronic computer to execute it."

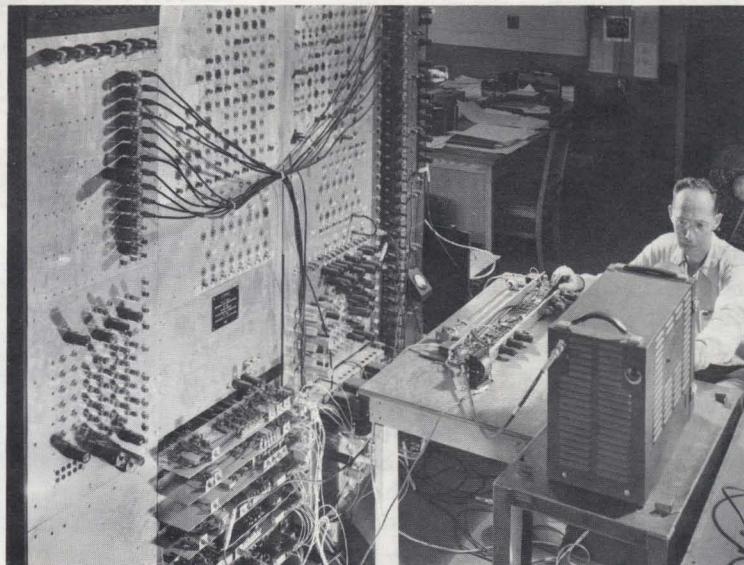
Arthur W. Burks, "From ENIAC to the Stored-Program Computer," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980.

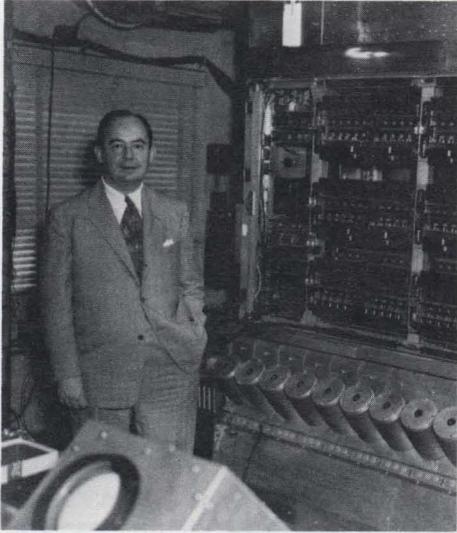
The mercury delay line memory, borrowed from radar to utilize as computer memory, was the key device that made the stored program practical. The ENIAC had only twenty words high-speed memory capacity, using expensive vacuum tubes—far too few to store programs and data. In contrast, each delay line could hold hundreds of words, with bits circulating as ultrasonic pulses in a column of mercury. When each bit reached the end of the column, it was converted to an electrical signal, where it was cleaned up and could be read.

Von Neumann's write-up of the EDVAC group's discussions

was widely circulated in draft. The Moore School's 1946 summer lecture series on the EDVAC design also helped publicize the idea of the stored program computer. The EDVAC, while still in its design stage, directly or indirectly influenced all postwar computer projects.

The EDVAC's theoretical design and construction stage lasted from 1944 to 1951.

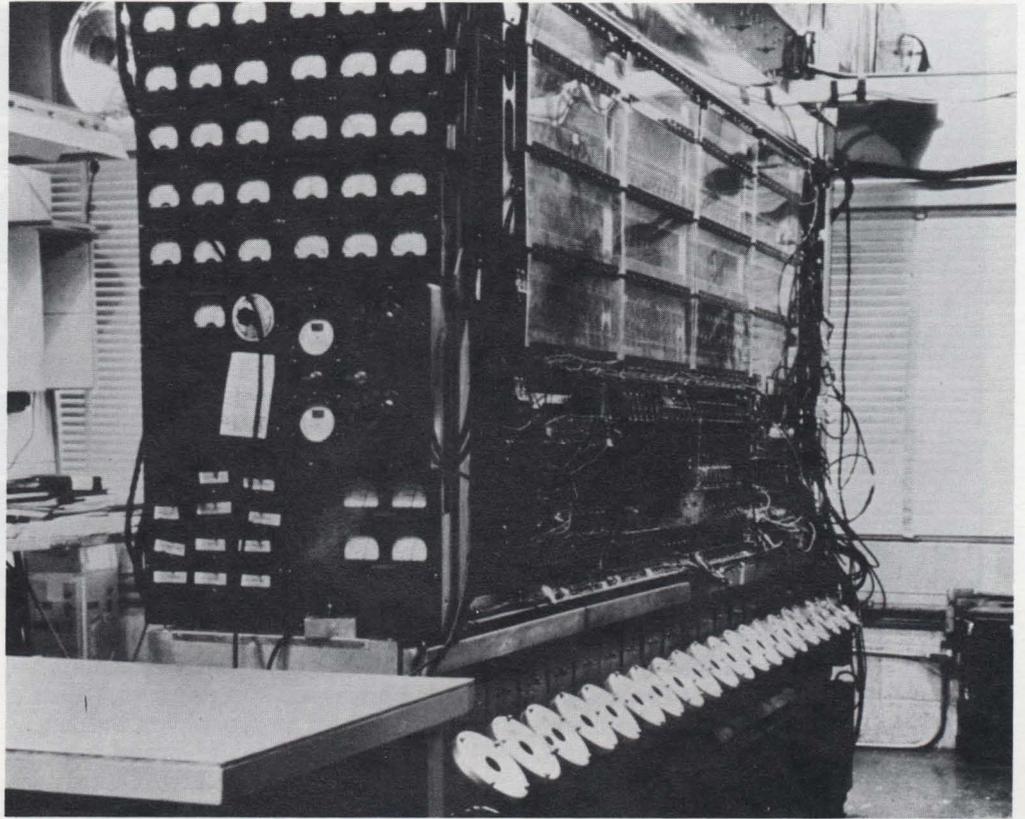




John von Neumann left the EDVAC project to return to the Institute for Advanced Study, bringing with him Arthur Burks and Herman Goldstine. The three elaborated stored program computer design with the draft of "Preliminary Discussions of the Logical Design of an Electronic Computing Instrument."

The IAS Computer introduced asynchronous operation. For fast memory, it used the Williams tube, a CRT memory developed at Manchester University. The Williams tube was used in serial mode at Manchester; the IAS Computer was first to use it in parallel.

One of the IAS Computer's most significant contributions was as a pattern for other computer projects. Julian Bigelow, who was the computer's chief designer, recounts: "Another feature of the arrangement for financial support [by military agencies and the Atomic Energy Commission] provided that, as sections of the computer were successfully developed, working drawings would be sent out by our engineering group to five other development centers supported by similar government contracts, notably to Los Alamos Laboratory, the University of Illinois, Oak Ridge National Laboratory, Argonne National Laboratory, and the Rand Corporation. For the first year or so this requirement that what we produced was in effect going to be duplicated at five distinguished laboratories elsewhere added to the anxieties of the IAS team, espe-



cially since these correspondents were mostly well established and supported by facilities and resources wholly lacking *chez nous*. We anticipated that any mistakes we might make in sending out piecemeal the fruits of our efforts would thereby be exposed to possibly hostile or competitive criticism, leaving us no place to hide, but in fact problems of this sort never arose, and communication with all people at these laboratories was entirely friendly and stimulating."

Julian Bigelow, "Computer Development at I.A.S. Princeton," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980.

The IAS computer.

"The EDSAC is based on principles first enunciated in an unpublished report . . . in which ideas for a machine known as the EDVAC were set out."

Maurice Wilkes "Programme Design for a High Speed Automatic Calculating Machine," Journal of Scientific Instruments 1949.

By 1949, a number of computers were underway. Maurice Wilkes, Director of Computation at Cambridge University, was the first to complete a machine with the first program running on May 6th of that year. Maurice Wilkes started the project on his return from the 1946 Moore School lectures on the EDVAC design. Returning to Cambridge University, he set up the Computation Laboratory and started work on a stored program computer. Wilkes used existing technologies to get a machine up and running. His decision on memory technology was characteristic of this design philosophy: **"We used the mercury delay-line because it was really the only thing you could count on at the time."**

Maurice Wilkes, gallery talk, at The Computer Museum, July 7, 1982

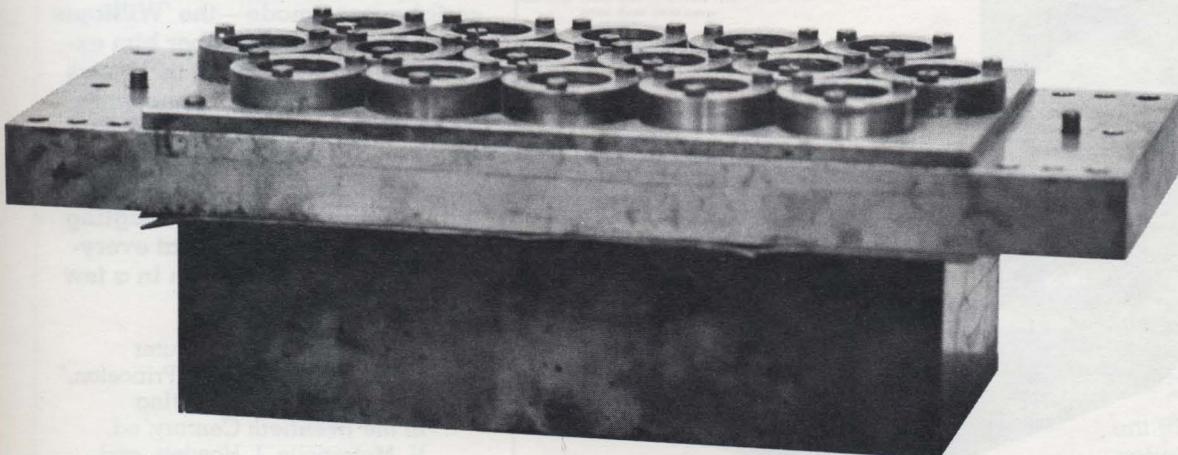
"We realized that building the machine was only the start of the project; that there was a great deal to be learnt about writing programs, about how to use the machine for numerical analysis, numerical calculation, and all the rest of it . . . As soon as we started programming, we found to our surprise that it wasn't as easy to get programs right as we had thought. Debugging had to be discovered. I can remember the exact instant when I realized that a large part of my life from then on was going to be spent in finding mistakes in my own programs."

Maurice Wilkes, Pioneer Computer Lecture, The Computer Museum, September 21, 1979

Valves (the English equivalent of vacuum tubes) on the EDSAC memory driver. Maurice Wilkes is on the back cover holding the memory driver's wiring. (On loan from the Science Museum, London.)



EDSAC memory delay lines plugged into this tank cover. (On loan from the Science Museum, London.)



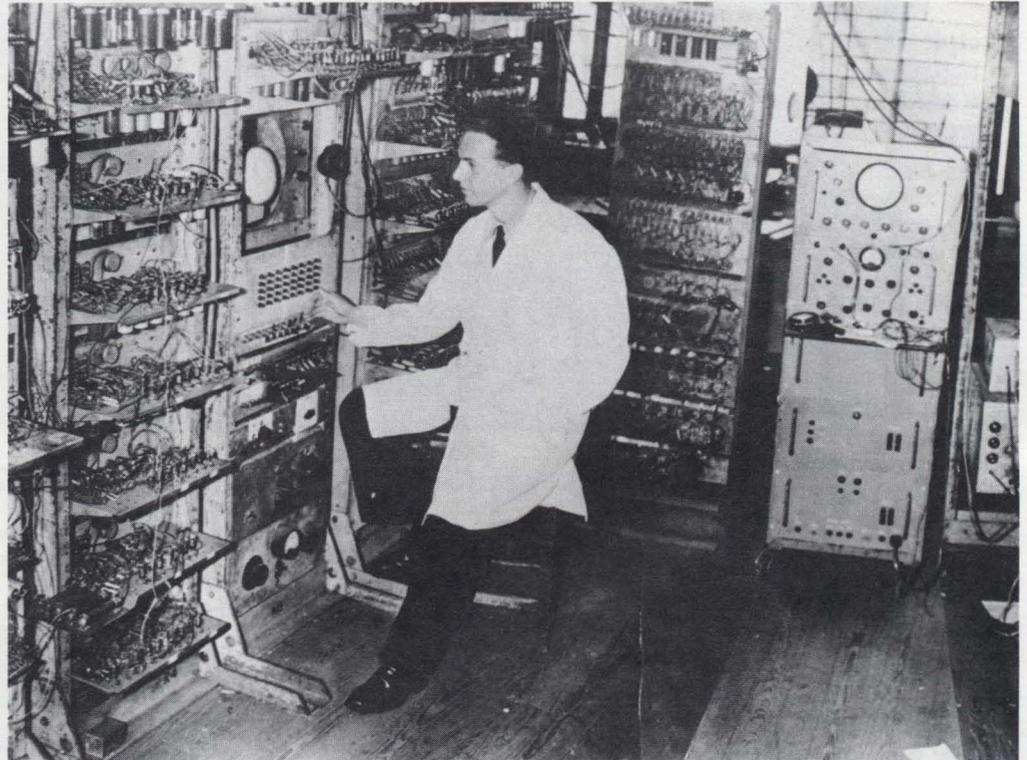
Graduate student Dai Edwards.
A Williams tube set in the machine
can be seen in the foreground.

Computer work began at Manchester University in late 1946. F. C. Williams and Thomas Kilburn's first project was to build a new kind of memory, one that was large enough to store programs and data, but faster than the mercury delay line. Several investigators, most notably Jan Rajchman of RCA, had been working on cathode-ray tube memory. Williams and Kilburn solved a major drawback to the CRT, i.e., that the charged spots that represented bits only stayed on the screen for a few instants before dissipating. "Looking back, it is amazing how long it took to realize the fact that if one can read a record once, then that is entirely sufficient for storage, provided that what is read can be immediately rewritten in its original position."

F. C. Williams and T. Kilburn,
paper presented at Manchester
University Computer Inaugural
Conference, 1951

The Manchester group built an experimental prototype to test the Williams tube. The "baby machine" ran its first program in June 1948. The machine was expanded in several stages, and the full-scale computer was complete in late 1949. Williams described its not-quite-automatic operation:

"The two-level store [fast Williams tube and slow magnetic drum] I have referred to was indeed



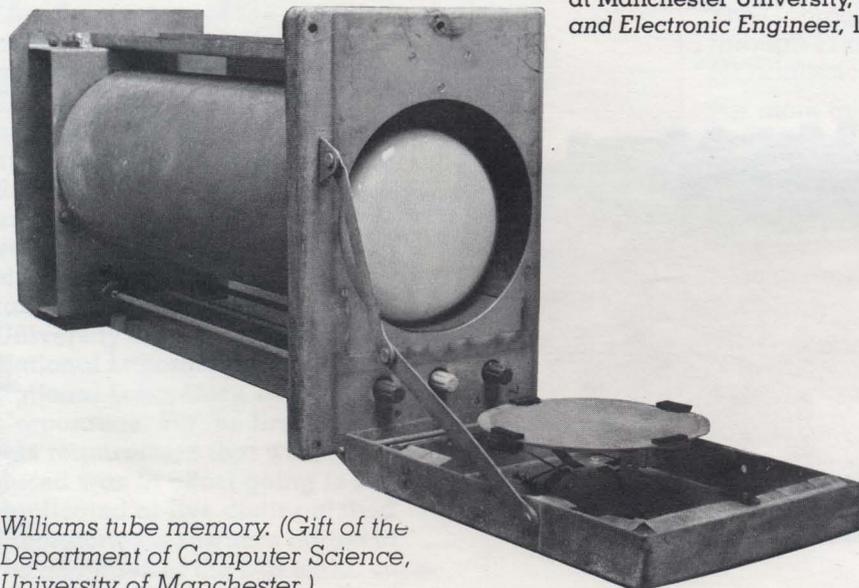
on two levels. The electronic store was in the magnetism room and the magnetic store in the room above. Transfers between the stores were achieved by setting switches, then running to the bottom of the stairs and shouting, 'We are ready to receive track 17 on tube 1.' The process was repeated for tube 2 and the machine set working. When the machine wished to disgorge information, it stopped and the reverse process was initiated."

F. C. Williams, "Early Computers at Manchester University, *Radio and Electronic Engineer*, 1975

Williams tube memory was borrowed by several computers of the day, including the IAS Computer. Julian Bigelow, head of engineering design for the IAS project, recalled his visit to see the Manchester Computer in its early state:

"My visit to Manchester was a delightful experience; F. C. Williams was a true example of the British 'string and sealing wax' inventive genius, who had built a primitive electronic computer from surplus World War II radar parts strictly on his own inspiration—in the middle of which were two cathode-ray tubes storing digits in serial access mode—the 'Williams memory.' I can remember him explaining it to me, when there was a flash and a puff of smoke and everything went dead, but Williams was unperturbed, turned off the power, and with a handy soldering iron, replaced a few dangling wires and resistors so that everything was working again in a few minutes."

Julian Bigelow, "Computer Development at I.A.S. Princeton," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980



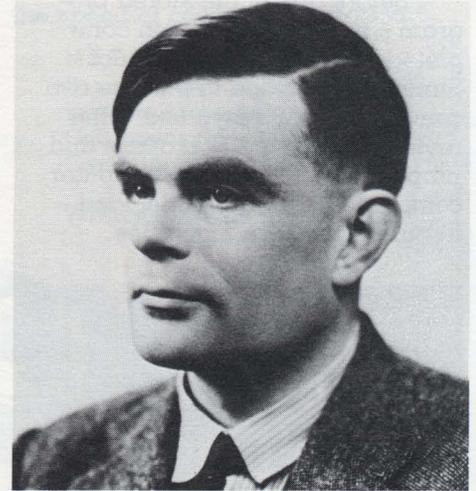
Williams tube memory. (Gift of the Department of Computer Science, University of Manchester.)

After the war, Britain's National Physical Laboratory began a computer project. Alan Turing, who had written a paper on machine intelligence in 1936 and participated in the Bletchley Park cryptanalytic effort, was the central figure in the early days of the NPL project. In the words of the NPL's director, "About twelve years ago, a young Cambridge mathematician, by name Turing, wrote a paper in which he worked out by strict logical principles how far a machine could be imagined which would imitate processes of thought. It was an idealized machine he was considering, and at that time it looked as if it could never possibly be made. But the great developments in wireless and electronic valves during the war have altered the picture. Consequently, Turing, who is now on our staff, is showing us how to make his idea come true."

Sir Charles Darwin,
BBC broadcast, 1946

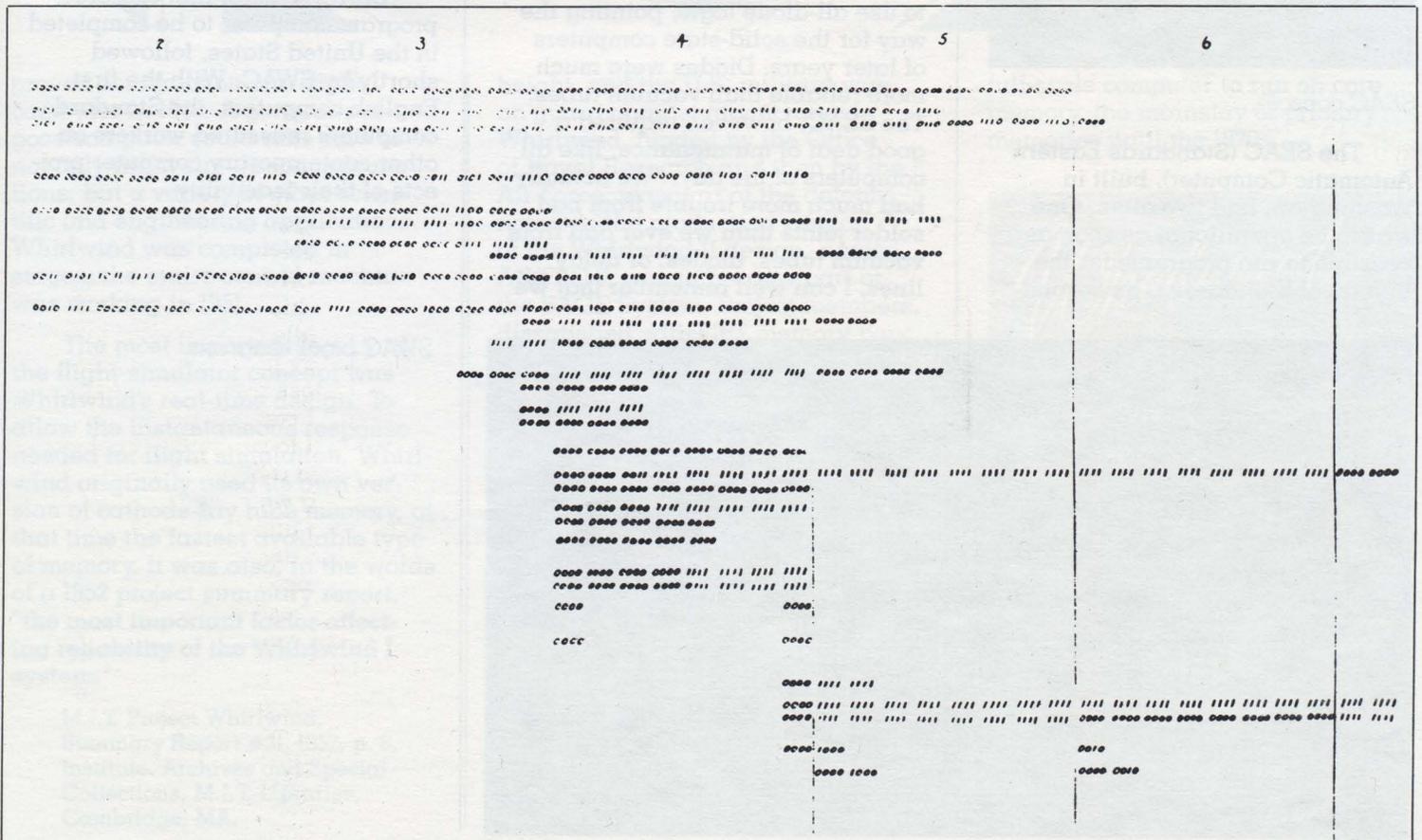
Turing designed several versions of a computer, but left the NPL in 1947. An NPL team directed by J. H. Wilkinson built a pilot version of the ACE, which embodied Turing's highly original design philosophy. Turing summed it up in a 1947 conference discussion: "We are trying to make greater use of the facilities available in the machine to do all kinds of different things simply by programming rather than by the addition of extra apparatus."

Discussion of "Transfer Between External and Internal Memory" by C. Bradford Sheppard, *Proceedings of a Symposium on Large-Scale Digital Calculating Machinery*, Cambridge, Mass., 1947.



From Alan Turing's ACE notebook. "In the ACE, we intend to represent all numbers in the binary system . . . Every number may be represented in the binary system by a sequence of digits each of which is either a zero or a one, and this provides us with a particularly simple method of representing a number electrically."

J. H. Wilkinson, Progress Report on the Automatic Computing Engine, Mathematics Division, National Physical Laboratory, 1948.



National Bureau of Standards SEAC and SWAC

Before any of the stored program computers had been completed, the National Bureau of Standards decided to procure two computers for its own use. After reviewing university projects and proposals from nascent computer companies, Standards decided to build their own machines.



SEAC console.

The SEAC (Standards Eastern Automatic Computer), built in Washington, had two aims. One was to be operational as soon as possible to run programs for the Bureau of Standards. The second

objective was to be a laboratory for testing components and systems, since the Bureau of Standards might be called on to set standards relating to computers.

SWAC (Standards Western Automatic Computer) was built at the Institute for Numerical Analysis in Los Angeles. Its main objective was to be finished as soon as possible, using as much already-developed technology as possible. Project leader Harry Huskey wrote, "The plan was to build a computer with the minimum of circuit development. Thus, the circuits in the arithmetic unit were derived from Whirlwind circuits, and the development of the memory circuits depended heavily on the published work of F. C. Williams of Manchester University."

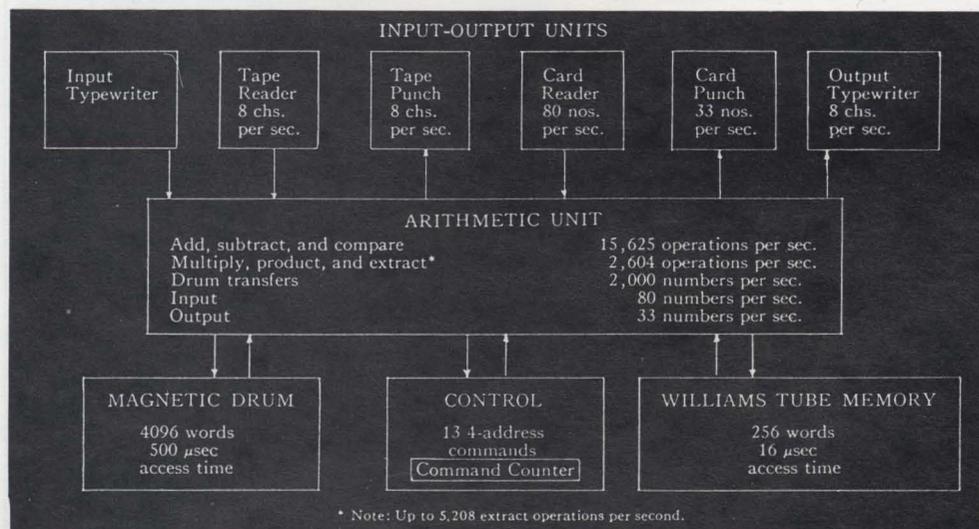
Harry D. Huskey, "The National Bureau of Standards Western Automatic Computer (SWAC)," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980

SEAC was the first computer to use all-diode logic, pointing the way for the solid-state computers of later years. Diodes were much more reliable than vacuum tubes. The SEAC, however, required a good deal of maintenance, like all computers of the day: "We actually had much more trouble from bad solder joints than we ever had from vacuum tubes, diodes, or delay lines. I can well remember that we

established two standard debugging techniques. After about two hours a day of preventive maintenance, we would start a test program running. Then we applied the 'stir with a wooden spoon' technique, which consisted of taking something like a wooden spoon and going around the computer, tapping everything you could see. If the test program stopped, you had found something. When that test was finally passed, we applied the Bureau of Standards' 'standard jump.' We were in a building with wooden floors that were not difficult to shake, so the standard jump consisted of jumping up in the air about 15 cm and coming down on the floor as hard as possible. If that test was passed, the machine was ready to tackle a computational program—and even more interesting bugs would show up."

Ralph J. Slutz, "Memories of the Bureau of Standards' SEAC," in *A History of Computing in the Twentieth Century*, ed. N. Metropolis, J. Howlett, and Gian-Carlo Rota, New York, 1980

SEAC was the first of stored program computer to be completed in the United States, followed shortly by SWAC. With the first English computers, the Standards computers reassured workers on other contemporary computer projects of their feasibility.



SWAC block diagram.

Whirlwind

In 1944, the Massachusetts Institute of Technology contracted with the Navy to build a universal aircraft flight simulator/trainer. Jay Forrester of the M.I.T. Servomechanisms Lab became director of the project. By 1945, the original conception of an analog machine was dropped, and the Navy ap-

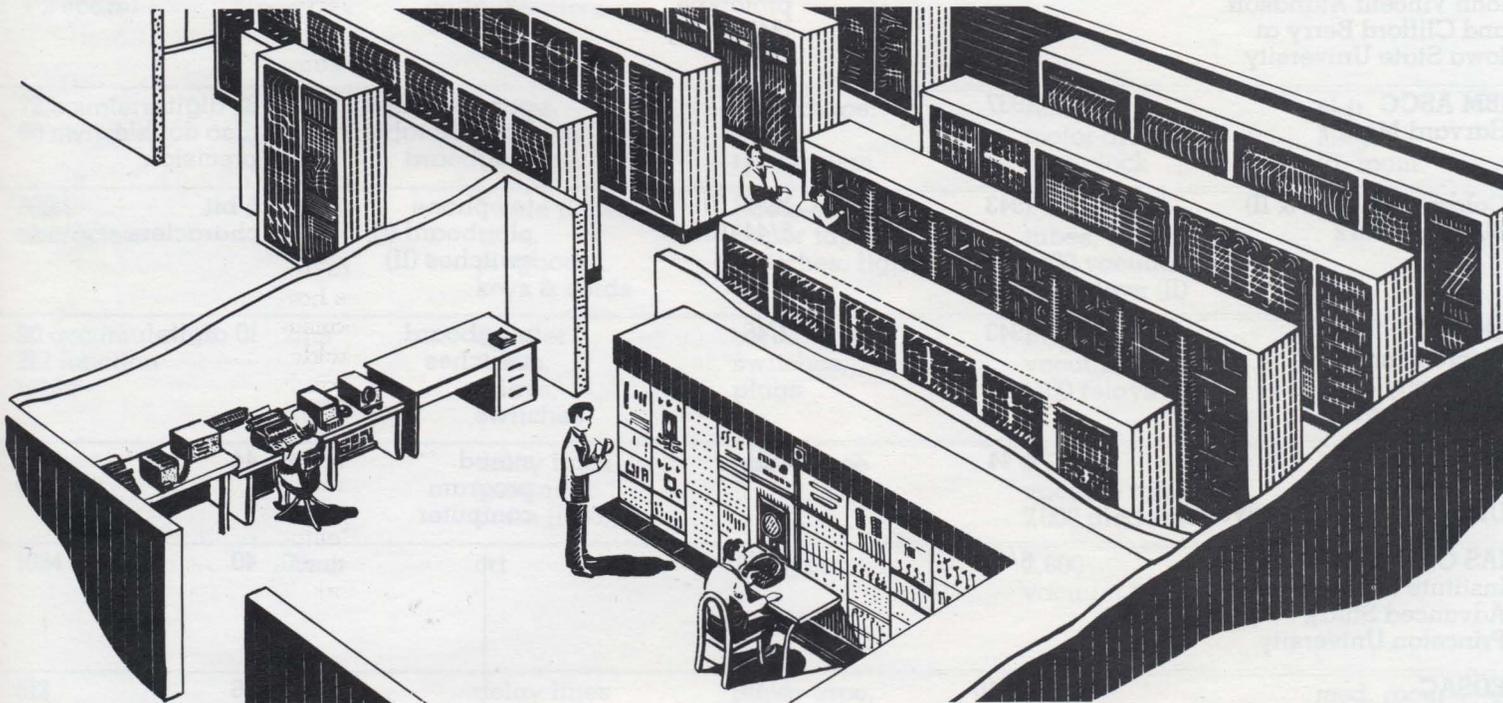
An elaborate system of marginal checking identified hardware problems before they affected computational accuracy.

At the same time, new military applications which demanded higher-than-ever reliability were emerging. The Cold War was at its

25 microseconds) thus increasing the speed of computer operation."

M.I.T. Project Whirlwind, Summary Report #35, 1953, p. 33. Institute Archives and Special Collections, M.I.T. Libraries, Cambridge, MA.

Whirlwind was thus the first



proved construction of a digital computer in 1946. A general-purpose computer could take care of not only flight simulation calculations, but a variety of other scientific and engineering applications. Whirlwind was completed in stages; the entire central machine was working in 1951.

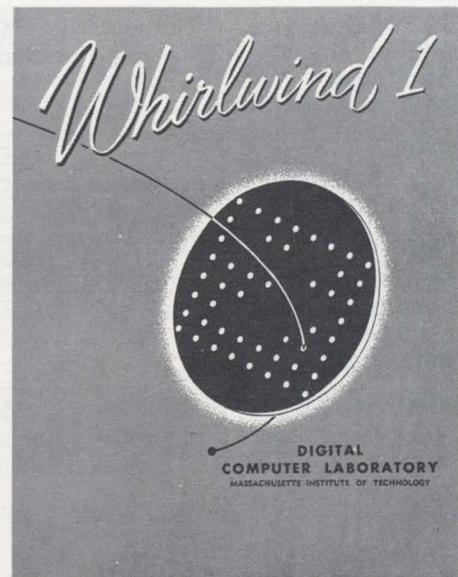
The most important legacy of the flight-simulator concept was Whirlwind's real-time design. To allow the instantaneous response needed for flight simulation, Whirlwind originally used its own version of cathode-ray tube memory, at that time the fastest available type of memory. It was also, in the words of a 1952 project summary report, "the most important factor affecting reliability of the Whirlwind I system."

M.I.T. Project Whirlwind, Summary Report #31, 1952, p. 6. Institute, Archives and Special Collections, M.I.T. Libraries, Cambridge, MA.

height, and the U.S. military was on guard against atomic attack. Whirlwind, funded by the Office of Naval Research and then by the Air Force, was part of the defense network; the production version of the Whirlwind II design, named AN/FSQ-7, was to become part of the SAGE System. Project members, dissatisfied with CRT memory performance, researched a substitute.

Several researchers in the late 1940s, including Jay Forrester, conceived the idea of using magnetic cores for computer memory. William Papian of Project Whirlwind cited one of these efforts, Harvard's "Static Magnetic Delay Line," in an internal memo. Core memory was installed on Whirlwind in the summer of 1953. "Magnetic-Core Storage has two big advantages: (1) greater reliability with a consequent reduction in maintenance time devoted to storage; (2) shorter access time (core access time is 9 microseconds; tube access time is approximately

full-scale computer to run on core memory, the mainstay of primary memories until the 1970s.



The Pioneer Computers

Comparative Statistics

	Start up	Completion	Program	Word length
Bell Labs Model I George Stibitz at Bell Telephone Laboratories	1939	10/39	4 function, complex arithmetic calculator	8 digits
Zuse Z3 Konrad Zuse	1939	1941	punched film	22 bits, flt. pt.
ABC John Vincent Atanasoff and Clifford Berry at Iowa State University	12/37	12/39 prototype 1942	fixed, equation solver	50 bits
IBM ASCC Harvard Mark I	1937	8/44	punched tape, function table, plugboard	23 digits also double precision
Colossus (Mark I & II) Bletchley Park	1943	12/43 (I) 5/44 (II)	telephone plugboard (I), switches (II)	5 bit characters
ENIAC Moore School, University of Pennsylvania	1943	2/46	plugboard, switches	10 digits
EDVAC Moore School, University of Pennsylvania	1/44	1951	stored program computer	44
IAS Computer Institute for Advanced Study, Princeton University	6/46	7/51		40
EDSAC Maurice Wilkes at Cambridge University	10/46	5/49		36
MANCHESTER U. MARK I Manchester University	1947	6/48 prototype 7/49		40
PILOT ACE National Physical Laboratory, Teddington, England	10/48	5/50		32
SEAC National Bureau of Standards	6/48	5/50		45
SWAC National Bureau of Standards Institute for Numerical Analysis	1/49	7/50		41
Whirlwind Servomechanisms Laboratory, MIT	1945	1951		16

In many cases, the material in this table was compiled from data sheets filled out by a person who worked on the machine. In the literature conflicting published data was found. The Museum requests corrections to this table and will keep the most accurate updated version on file.

Memory size (words)	Add time	Memory type [secondary]	I/O	Technology	Floor space est. sq. ft.
4 working registers	6s for complex x (4 products)	none	Teletype or paper tape	450 relays	50
64	2s	relays	punched film, keyboard, lights	2600 relays	100
2 × (30 + 2 spare)	32 in 1s	drum of capacitors	cards	vacuum tubes	12.5
72 counters 60 switches	.3s	relays, switches	paper tape, cards, typewriters	relays, motor-driven cam, clock	51 ft long, lg. room
500 characters	.2ms	5 hole paper tape, plugboard, keys & cords	photo-electric paper tape, switches, lights	1500 vacuum tubes, relays (I) 2400 vacuum tubes 800 relays (II)	200 (II)
20 accumulators, 312 function table	.2ms	counter tubes, relays, switches	cards, lights, switches, plugs	18,000 vacuum tubes, 1500 relays	1,000
1024 (8 × 128)	.85ms	delay lines, [magnetic drum (1953)]	paper tape	3,500 vacuum tubes, 7,000 diodes	400
1024	.09ms	crt	Teletype	2,600 vacuum tubes	100
512	1.4ms	delay lines	paper tape, teleprinter	3,000 vacuum tubes	med. room
128 + 1024	1.8ms	crt, [magnetic drum]	paper tape, teleprinter, switches	1,300 vacuum tubes	med. room
352	.54ms	delay lines	cards	800 vacuum tubes	12
512 + 512	.86ms	crt, delay lines, [magnetic tape & wire]	paper tape Teletype	1,290 vacuum tubes, 15,800 diodes	150
256	.064ms	crt, magnetic drum	cards, paper tape	2,000 vacuum tubes 2,500 diodes	60
2048	.05ms	crt, core (1953), [magnetic drum & tape]	crt, paper tape, magnetic tape	4,500 vacuum tubes, 14,800 diodes	3,100 lg. rooms

Warning: Use of any data on this table without prior checking with the Museum may lead to the proliferation of inaccuracies.

Primary source books with excellent bibliographies, guiding the reader to great numbers of primary and secondary sources:

C. Gordon Bell and Allen Newell, *Computer Structures: Readings and Examples*, New York, 1971.

B. V. Bowden, Editor, *Faster than Thought, A Symposium on Digital Computing Machines*, New York, 1966.

N. Metropolis, J. Howlett, and Gian-Carlo Rota, Editors, *A History of Computing in the Twentieth Century*, New York, 1980.

Brian Randell, Editor, *The Origins of Digital Computers, Selected Papers*. Third Edition, Berlin, 1982.

Bell Telephone Laboratories Model I

George R. Stibitz, videotape of lecture at The Computer Museum, 1980.

George Robert Stibitz papers. Dartmouth College Library.

Archives, Bell Telephone Laboratories. G.R. Stibitz, "Calculating With Telephone Equipment." Paper presented at Mathematical Association of America meeting, Hanover, N.H., 1940.

Zuse Z1, Z3

A replica of the Z3 is on exhibit at the Deutsches Museum, Munich.

Konrad Zuse, videotape of lecture at The Computer Museum, 1981.

K. Zuse, *Calculator for Technical and Scientific Calculations Designed According to a Theoretical Plan*. Distributed by the Office of the Publication Board, Department of Commerce, Washington, D.C. (n.d.).

ABC

A simplified model of the Atanasoff-Berry Computer built by J. V. Atanasoff is on exhibit at The Computer Museum.

J.V. Atanasoff, videotape of lecture at The Computer Museum, 1980.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

IBM ASCC (Harvard Mark I)

Part of the IBM ASCC is on exhibit at the Harvard Computation Laboratory.

Records of the Computation Laboratory. University Archives, Harvard University, Cambridge, Mass.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

Colossus

T. H. Flowers, videotape of lecture at The Computer Museum, 1981.

See also Randell.

ENIAC

Parts of the ENIAC are on exhibit at the University of Michigan, the National Museum of American History, Smithsonian Institution, and at The Computer Museum.

J. G. Brainerd, videotape of lecture at The Computer Museum, 1981.

Arthur C. Burks, videotape of lecture at The Computer Museum, 1982.

R.F. Clippinger, audiotape of lecture at The Computer Museum, 1982.

"The ENIAC Film." Footage of the ENIAC operating in 1946, with introduction and narration by Arthur Burks. Videotape produced by Arthur Burks and The Computer Museum, 1982.

ENIAC Archives, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

ENIAC Trial Records. United States District Court, District of Minnesota, Fourth Division: Honeywell, Inc. v. Sperry Rand Corp. et al., No. 4-67 Civ. 138, decided October 19, 1973.

F. Robert Michael, "Tube Failures in ENIAC," *Electronics* 20, 1947.

H.W. Spence, "Systematization of Tube Surveillance in Large Scale Computers," *Electrical Engineering* 70, 1951.

EDVAC

EDVAC Archives, Moore School of Engineering, University of Pennsylvania, Philadelphia.

Archives, Division of Mathematics,

National Museum of American History, Smithsonian Institution, Washington, D.C.

Donald Eadie, "EDVAC Drum Memory Phase System of Magnetic Recording," *Electrical Engineering* 72, 1953.

S. E. Gluck, "The Electronic Discrete Variable Computer," *Electrical Engineering* 72, 1953.

IAS Computer

The IAS Computer is on exhibit at the National Museum of American History, Smithsonian Institution, Washington, D.C.

Mathematics and Natural Sciences Library, Institute for Advanced Study, Princeton, N.J.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

EDSAC

Parts of the EDSAC are on exhibit at The Computer Museum.

M. V. Wilkes, videotape of lecture at The Computer Museum, 1979.

"The EDSAC Film." Produced by Cambridge University Mathematics Laboratory, 1951; with introduction and narration by M. V. Wilkes, 1976.

M. V. Wilkes and W. Renwick, "An Ultrasonic Memory Unit for the EDSAC," *Electronic Engineering* 20, 1948.

Manchester University Mark I

Parts of the Manchester University Mark I are on exhibit at Manchester University. D.B.G. Edwards, videotape of lecture at The Computer Museum, 1981.

F. C. Williams and T. Kilburn, "A Storage System for Use with Binary Digital Computing Machines," *Proceedings of the IEE* 96, part 2, 1949.

F. C. Williams, T. Kilburn, and G. C. Tootill, "Universal High-Speed Digital Computers: A Small-Scale Experimental Machine," *Proceedings of the IEE* 98, part 2, 1951.

Pilot ACE

The Pilot ACE is on exhibit at the Science Museum, London.

J. H. Wilkinson, videotape of lecture at The Computer Museum, 1981.

Archives, National Physical Laboratory, Teddington, England.

E. A. Newman, D. O. Clayden, and M. A. Wright, "The Mercury-Delay-Line Storage System of the ACE Pilot Model Electronic Computer," *Proceedings of the IEE* 100, part 2, 1953.

NBS SEAC

Parts of the SEAC are on exhibit at the National Bureau of Standards Museum. Library Division, National Bureau of Standards, Washington, D.C.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

National Bureau of Standards, MDL Staff, "The Incorporation of Subroutines into a Complete Problem on the NBS Eastern Automatic Computer," *Mathematical Tables and Other Aids to Computation* 4, 1950.

National Bureau of Standards, Electronic Laboratory Staff, "The Operating Characteristics of the SEAC," *Mathematical Tables and Other Aids to Computation* 4, 1950.

S. N. Alexander, "The National Bureau of Standards Eastern Automatic Computer," *Proceedings, Joint AIEE-IRE Computer Conference*, Philadelphia, Pa., 1951.

Alan L. Leiner, "Provisions for Expansion

in the SEAC," *Mathematical Tables and Other Aids to Computation* 5, 1951.

Ernest F. Ainsworth, "Operational Experience with SEAC," *Proceedings of the Joint AIEE-IRE-ACM Computer Conference*, New York, December 10-12, 1952.

S. Greenwald, "SEAC Input-Output System," *Proceedings of the Joint AIEE-IRE-ACM Computer Conference*, New York, December 10-12, 1952.

Ruth C. Haueter, "Auxiliary Equipment to SEAC Input-Output," *Proceedings of the Joint AIEE-IRE-ACM Computer Conference*, New York, December 10-12, 1952.

James L. Pike, "Input-Output Devices Used with SEAC," *Proceedings of the Joint AIEE-IRE-ACM Computer Conference*, New York, December 10-12, 1952.

Sidney Greenwald, R.C. Haueter, and S.N. Alexander, "SEAC," *Proceedings of the IRE* 41, 1953.

NBS SWAC

Parts of the SWAC are on exhibit at the National Bureau of Standards Museum and the Museum of Science and Industry, Los Angeles.

Library Division, National Bureau of Standards, Washington, D.C.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

H. D. Huskey, "Characteristics of the Institute for Numerical Analysis Computer," *Mathematical Tables and Other Aids to Computation* 4, 1950.

H. D. Huskey, R. Thorensen, B. F. Ambrosio, and E. G. Yowell, "The SWAC—Design Features and Operating Experience," *Proceedings of the IRE* 41, 1953.

Whirlwind

Parts of Whirlwind are on exhibit at the National Museum of American History, Smithsonian Institution, Washington, D.C., and The Computer Museum.

Jay Forrester, videotape of lecture at The Computer Museum, 1980.

"See It Now: Interview with Whirlwind." Excerpt from Edward R. Murrow's CBS news program, 1951.

"Making Electrons Count." Film produced by MIT, 1953.

MIT Servomechanisms Laboratory Technical Publications File, 1944-1968, (AC-34); MIT Digital Computer Laboratory Records, 1944-1959 (80-36); and Magnetic Core Memory Records, 1932-1977 (MC-140). Institute Archives and Special Collections, M.I.T. Libraries, Cambridge, Mass.

Corporate Archives, MITRE Corporation, Bedford, Mass.

Archives, Division of Mathematics, National Museum of American History, Smithsonian Institution, Washington, D.C.

S. H. Dodd, H. Klemperer, and P. Youtz, "Electrostatic Storage Tube," *Electrical Engineering* 69, 1950.

Jay W. Forrester, "Digital Information Storage in Three Dimensions Using Magnetic Core," *Journal of Applied Physics* 22, 1951.

R. R. Everett, "The Whirlwind I Computer," *Electrical Engineering* 71, 1952.

William N. Papian, "A Coincident-Current Magnetic Memory Cell for the Storage of Digital Information," *Proceedings of the IRE* 40, 1952.

William N. Papian, "The MIT Magnetic-Core Memory," *Proceedings of the Joint IRE-AIEE-ACM Computer Conference*, Washington, D.C., 1953.

J. W. Forrester, "Multicoordinate Digital Information Storage Device," U.S. Patent 2,736,880, issued February 28, 1956.

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SYMPOSIUM ON ARCHIVING THE HISTORY OF COMPUTING

On May 5 and 6, 1983, the Museum will host a symposium that addresses questions on archiving the history of information processing. The purpose is to share information about activities planned and underway at the museum, institutes, libraries, government agencies, corporations, universities, and individuals.

Attendance will be limited in order to gain a broad cross-section of information. Anyone interested should contact Chris Rudomin at The Computer Museum, (617) 467-7570.

Annual Anniversary
Dinner and Lecture
May 5, 1983

Grace Hopper
on the
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April 14, 1983

WATCH THIS SPACE FOR THE ANNOUNCE- MENT OF THE SPRING LECTURE SERIES

IN THE NEXT REPORT.

A newsbrief of the collection

Two important loans were revealed during Maurice Wilkes' recent gallery talk on his reminiscences of early computing: a mercury memory tank cover and memory driver from Cambridge University's EDSAC. The memory driver (pictured) was used on the mercury delay line memory. Wilkes was the Director of Computation at Cambridge, where the EDSAC ran its first program in May of 1949.

The memory driver and the mercury memory tank cover, on loan from the Science Museum, London, are exhibited on the Pioneer Computer Timeline.

The
Computer
Museum

One Iron Way
Marlboro
Massachusetts
01752

Dear Members, Friends and Newcomers to The Computer Museum:

December 23, 1982, marks the Museum's first birthday as an independent non-profit charitable foundation. During this year the Museum has put together a number of programs that will serve its members.

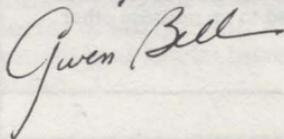
The number of exhibition galleries is growing with a new one opening in the spring. The pioneer lecture series, that will feature Grace Hopper on April 14th, is supplemented with spring and fall Sunday afternoon talks, called "Bits and Bites". A library and photo archive is available for use by the members, and our Museum store is growing in size and diversity.

This is our first catalog sampling a variety of items that can be found in the Museum shop itself. We hope that you will enjoy our offering of materials selected by Museum Members for Museum Members. If you are not already a Member, we hope that you will consider joining so that you can take advantage of the 10% Museum Membership discount and all the Museum has to offer.

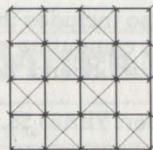
- Subscription to our quarterly, **The Computer Museum Report**.
- Invitations to events and openings.
- Announcements of lectures, seminars and excursions.
- Use of the library and photo archives.

Cordially,

Gwen Bell
Director



P.S. I want to thank you for your purchases from this catalogue. They help support the exhibitions and programs of The Computer Museum.



Identify with the Museum

The Museum's logo—the core memory—has been adapted into ties and scarfs. And for the purist the Museum's "flea market" has real core planes.

Four inch square 64 x 64 Core Planes. Perfect for mounting on the office wall, use with overhead projectors, panning for gold, and as a special gift for the computer buff.

Order: CORE \$4.75

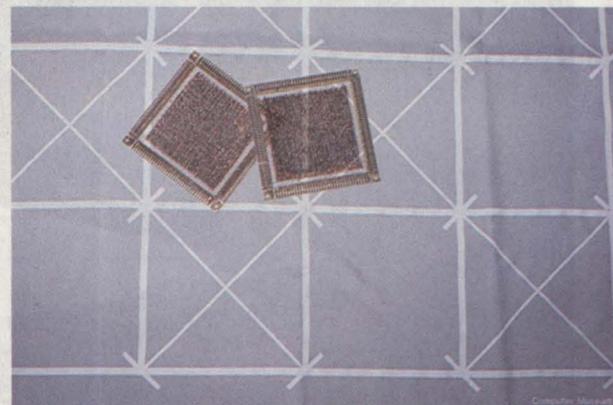
Classy 27 inch square 7 x 7 core plane Scarf. With a grey background, the white cores provide an abstract pattern bound to gain compliments from the "designer" and "computer" crowd.

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Classic Navy Blue Tie with Silver Woven Cores.

Both tie and the core design are produced by a Jacquard-like method with the pattern coded on tapes controlling the weaving. This announcement precedes delivery, in the spirit of the industry!

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Silicon Valley Genealogy.

A 17 x 34 inch poster traces the evolution of silicon valley's people and companies from 1946 to 1981. The information is as rich and dense as a chip.

Order: SEM81 \$5.00

Chocolate Calculator. Four ounces of solid chocolate made by a small company in Arlington, Massachusetts, who were awarded the distinction of best chocolate in Boston by Boston Magazine. Useful gift for people who complain that they have too many things already.

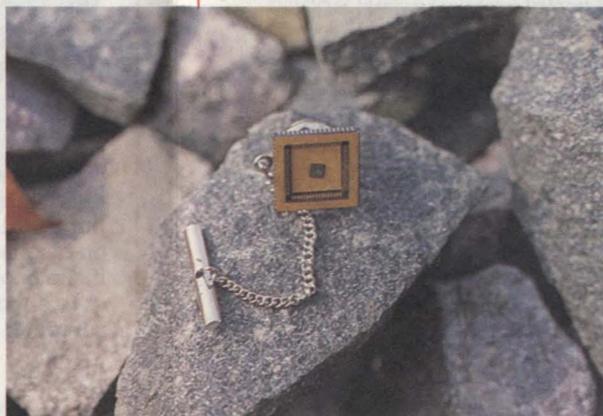
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The New Alchemists by Dirk Hanson is a quick, easily understood insightful shortcut to understanding the electronics culture in California. But the first four chapters on history just don't come up to snuff.

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Gold **Chip Earrings** are our Exhibit Coordinator, Jamie Parker's standard wear in the galleries—at The Computer Museum and all the other museums she loves to visit. (Pierced ears only.)

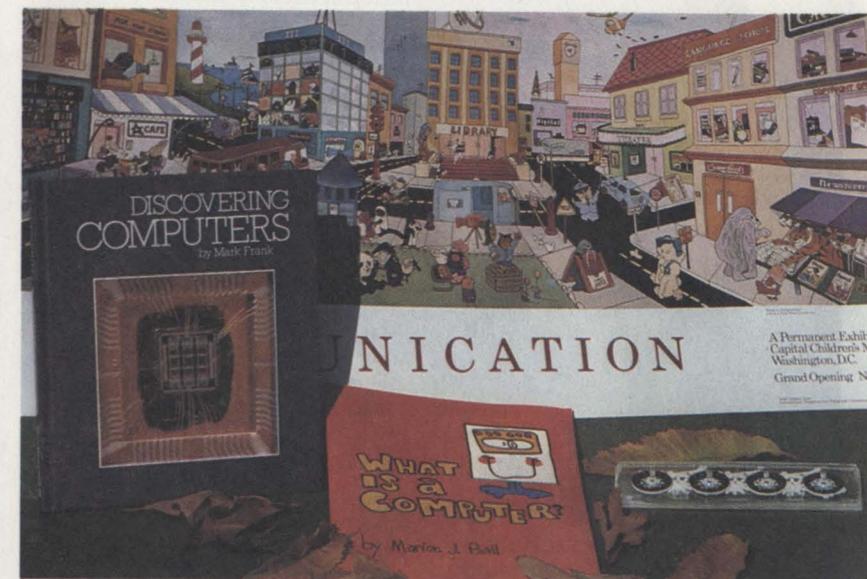
Order: CHEAR \$16.50

Gwen Bell wears her **INTEL '75 0785 Stickpin** with basic black. Her mother and daughter also wear theirs just because they look nice.

Order: INPIN \$12.95



CHIP JEWELRY Individually handmade from exquisite industrially produced integrated circuits.



Communications. Your favorite animals illustrate this poster showing virtually every kind of communication. Designed at the Capitol Children's Museum, we thought it would be a treat for all the big computer kids as well.

Order: COM82 \$4.00

What is a Computer? by Marion Ball is a delightfully illustrated book for the primary school age. It's also an introduction into computer history with explanations of cards and core memory. Soft cover, 92 pages.

Order: BAL72 \$10.00

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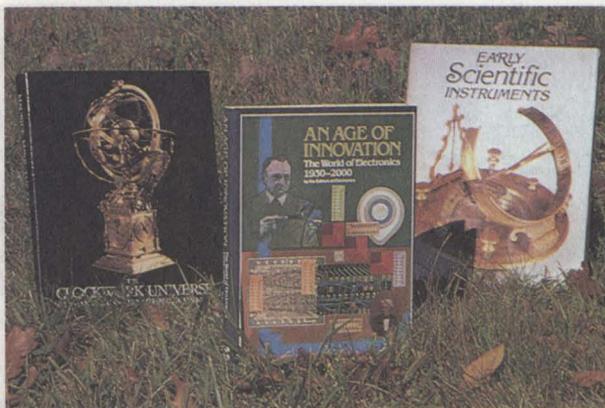
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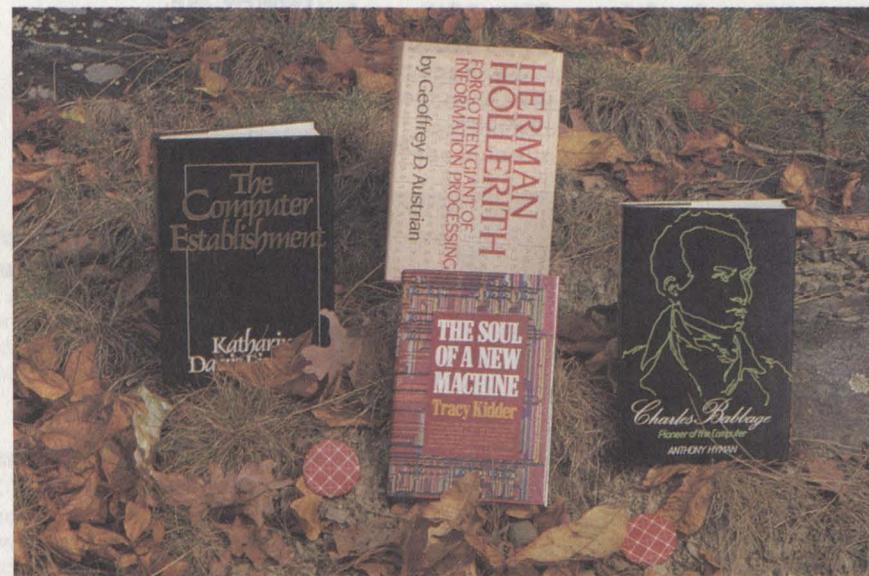
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