THE COMPUTER MUSEUM REPORT

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Howard Aiken and Lt. Grace Hopper

Contents

THE COMPUTER MUSEUM

The Computer Museum is a non-profit 501(c)3 foundation that chronicles the evolution of information processing through exhibitions, archives, publications, research, and programs.

It is conveniently located minutes from Logan International Airport and just a short walk from Boston's financial district and historic landmarks such as Faneuil Hall and the Freedom Trail.

Museum Hours: The Museum hours are 11 AM–6 PM, Wednesday, Saturday, and Sunday and 11 AM–9 PM, Thursday and Friday. It is closed Mondays, Tuesdays, Christmas, New Years, and Thanksgiving.

Museum Membership: The Museum offers both corporate and individual memberships; individual membership categories range from $30.00 to $4,096.00 and Corporate Membership from $1,000 to $10,000.

All members receive a membership card, free subscription to The Computer Museum Report, a 10% discount on merchandise from The Computer Museum Store, free admission and invitations to Museum previews. For more information, contact Membership Coordinator at The Computer Museum, 300 Congress Street, Boston, MA 02210, (617) 426-2800.

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The Director's Letter

The relationship between a museum and its members is always an important one, but at The Computer Museum, I think it's very special. A variety of new projects and services are now underway that illustrate our unique association.

Many of the Museum's lectures are being made available to you on cassette tape. Chip Mann, a Museum member who heads up an organization called Powersharing Inc., records those talks that are both interesting and appropriate for audio cassette (computer graphics presentations are not very good candidates for a purely audio tape) and is reproducing them for sale through The Computer Museum Store. The talks by Adam Osborne and Regis McKenna, now available, provide fascinating insights into contemporary marketing issues from totally different perspectives. The third tape now available, the story of how "Spacewar!" was developed at MIT, is also entertaining and instructive. For those of you who commute, these tapes are good alternatives to specialized news and talk shows. A regular subscription to the tapes can provide members with an "All Things Considered on Computing."

The Museum needs your valuable skills and talents as volunteers—not just at the Museum, but wherever you are. What kind of help does the Museum need?

Eyes and ears can let us know about appropriate additions to the collection, such as early personal computers, specialized calculators and slide rules, core memory stacks and planes (for a definitive collection), photos and films of people and machines.

Specialized programming for new interactive exhibits is a continual need. For example, a good p.c. simulation of a working IBM 1401 is on the wish list, as are simulations demonstrating why the Cray architecture is so fast, showing an election forecast, and other applications that illustrate the evolution of the industry. Here's an opportunity to do some programming just for the fun of it.

And, for those of you who are nearby, on-site volunteers to assist our interpreters in the galleries with visitors and to work behind-the-scenes would be a great help. At present, we have three very special such volunteers. Skip Hamel comes in almost every Thursday and Friday to help keep the exhibits in shape—adding, repairing and sprucing. Alan Sadowski, a member of the Adage Users group, and Neil Day, a high school junior, work many Friday nights and weekends programming the rendering of the "teapot" image processing exhibit. Without such help, the Museum would not be able to accomplish the tasks that are before us.

Special events, such as the May 3rd Benefit, also require volunteers. Susan Poduska, Chris Wilson, Fontaine Richardson, Wendy Germain, Jim Pompa, Maurice Dettman, Connie Bachman, Debbie Kramer, and Mary McKenney have signed on to make sure the party happens with flair *and* a positive cash flow for the Museum.

A second annual Computer Museum Attic Sale and Antique Show is being planned for Sunday, September 22. Some of the better items will be listed in the August Report so that members can participate in the sale from afar. Contributions for this are welcomed.

Some of our best ideas have come from you, the Museum members. Please let me know what can be done to make the Museum serve your needs and your goals for "the industry's attic and showcase."

Gwen K Bell

The young Howard Aiken.
(Photo courtesy of Mrs. Mary Aiken)

Howard Hathaway Aiken
The Life of a Computer Pioneer

by Gregory W. Welch

On August 14, 1944, Thomas J. Watson, president of the International Business Machines Corporation (IBM), publicly presented Harvard University with the IBM Automatic Sequence Controlled Calculator (ASCC).[1] Top brass from IBM, Harvard, and the U.S. Navy addressed the assembled press corps. Six-page, glossy brochures describing the machine and its development were distributed. It was a grand occasion.

The ASCC represented a tremendous advance for science and industry. It was the result of a long, cooperative effort between IBM and Harvard, and was already proving its worth: the Navy was using the calculator in connection with World War II. The public announcement of this engineering feat heralded what is now termed the "Information Age." Press reports sparked the public's imagination to consider a world full of automatic machines performing tasks formerly delegated to man. Despite the many people involved with and affected by the ceremony, the moment belonged, more than to anyone else, to one man.

The Harvard Mark I, as the machine was commonly known, was the brainchild of 44-year-old Harvard physicist, Howard Hathaway Aiken. Aiken had given birth to the project eight years before while working on his Harvard Ph.D. thesis. He and many of his colleagues were confounded by mathematical problems which required an immense amount of calculations. The idea of a machine which would perform vast calculations automatically was appealing to them. Consequently, Aiken embarked on the design of such a machine. Although the ASCC had been operating around-the-clock for several months for the Navy in connection with the war effort, the August 14th ceremony officially recognized the fruition of his effort.

The Mark I was only the first in a series of machines which Aiken was instrumental in designing. It was followed by three successors: the Mark II, III, and IV. In addition to designing computers, Aiken worked to increase the facilities of the Harvard Computation Laboratories and to establish a curriculum in information processing technology, both on a practical and a theoretical level. He also consulted for private industries and government agencies, travelled widely advocating international cooperation in the field of computing, and received many decorations for his work. Aiken worked to provide an environment in which computer science, indeed all sciences, could flourish. To appreciate his contributions one must examine the full scope of Aiken's work in the context of his life.

* * *

Howard Hathaway Aiken was born on March 8, 1900 in Hoboken, New Jersey.[2] While still a young boy, his family moved to Indianapolis, Indiana, where he attended grade school. His parents were of little means, and after his father's death, Howard had to work to help support his mother. When he finished grade school Aiken went to work for the Indianapolis Light and Heat Company as an electrician's helper. Eager to continue his education, he pursued a high school diploma through correspondence courses. Eventually, he was able to work the night shift and attend public school during the day. He received his diploma in 1919 from the Arsenal Technical High School in Indianapolis. The next year he was admitted to the University of Wisconsin in Madison to study electrical engineering. His experience as an electrician's helper came in handy in his academic work, and enabled him to find employment to pay for his schooling. While studying at the University of Wisconsin Aiken worked as the Watch Engineer on the night shift for the Madison Gas and Electric Company. In 1923 the University of Wisconsin awarded him a Bachelor's Degree of Science.[3]

Upon graduation from college, Aiken's career accelerated. The Madison Gas and Electric Company promoted him to the position of Engineer with the responsibility of redesigning and rebuilding the company's electric power plant. They next assigned him to oversee the construction of a 3-million-cubic-foot gas storage facility. Whether he became restless or his employers could not keep him supplied with challenging projects is unclear. In 1926 Aiken moved on. He took employment with the Central Station Division of the Westinghouse Electric and Manufacturing Company where his tasks ranged from product application to power plant design. In 1928 he left Western Electric to become a District Manager for the Line Material Company of Detroit to seek ever greater challenges and responsibilities. However, he found, as many engineers discover, that he was moving further from the activities he enjoyed.[4] Consequently, in 1931 he returned to school to study physics.

For a year he pursued a Ph.D. at the University of Chicago, but he found it to be "a lousy institution."[5] The next year he moved to Cambridge, Massachusetts to enroll in the graduate program of Harvard's Division of Applied Physics and Applied Sciences. Aiken earned his M.S. in 1937, and his Ph.D. in 1939. His dissertation, "Theory of Space Charge Conductions," dealt with the properties of vacuum tubes—devices in which electric currents are passed across an empty space between two metal contacts. The mathematical complexities involved in describing space charge conduction made calculating solutions to his problems impossible.[6] This diffi-

(Photo courtesy of Mrs. Mary Aiken)

culty led to Aiken's decision to build an automatic calculator.

From 1936 to 1937, Aiken became increasingly interested in automatic calculators. During a discussion with colleagues on the need for a powerful automatic calculator at Harvard, Professor Harlow Shapley, Director of the Harvard Observatory, informed Aiken of a project addressing these problems with IBM office machines at Columbia University.[7] The IBM machines could perform simple mathematical operations (addition, subtraction, multiplication, and division) upon information encoded in holes punched on paper cards. These machines were controlled by "wired plug boards" that had to be rewired for each different calculation. The prospect of hooking together several such machines under a central automatic control unit to perform complex calculations intrigued Aiken. During the summer of 1937, he began investigating previous attempts to build mechanical aids to computation. He read about many efforts, from the earliest attempt at a mechanical calculator by the 17th-century mathematician, Blaise Pascal, to the contemporary differential analyzers and office calculators. Of all these efforts, Aiken was most interested in the work of the 19th-century Londoner, Charles Babbage.

Building on Baggage

In 1822 Babbage had built a machine called the Difference Engine for the calculation of mathematical tables. This machine was a mechanical device capable of calculating the values of a function with an accuracy of up to six digits. It did this by a method of successive additions. Upon completing the machine, Babbage successfully acquired, with the aid of his friend, the Duke of Wellington, a series of government grants totalling 12,000 English pounds.[8] These grants were for the construction of a larger, more powerful Difference Engine, a machine capable of calculating tables, particularly for navigation, with an accuracy of 26 digits.[9] However, this machine was never completed. Instead, Babbage became obsessed with producing an even more ambitious machine, the Analytic Engine. In a paper of December 26, 1837, "On the Mathematical Power of the Calculating Engine," Babbage described the organization of a machine which could perform general calculations under automatic control. The described machine had the basic structure of a modern computer: a processor, a memory, and input and output devices. It was to have a "Mill," which would control the machine's operation and perform calculations according to instructions encoded on punched paper cards, a "Store" for saving information, and a printing device for the output of results. Babbage and his friend, Lady Ada Lovelace, daughter of poet Lord Byron, saw the vast potential for this machine to perform a wide variety of calculations independent of human intervention. Babbage's efforts to improve the machine's design never ceased. However, his dreams proved too advanced for the metal-working technology of his time. The machine was never completed.

Aiken saw the implications of Babbage's work, and his calculator partly reflected the design of Babbage's Analytic Engine. He also took Babbage's experience building the Analytic Engine to heart, and decided it would be best to build his calculator with components which were proven reliable. Consequently, his calculator used electromechanical components, rather than vacuum tubes. The culmination of his research was a paper, "Proposed Automatic Calculating Machine," written at the end of summer of 1937. In it he outlined the necessity for an automatic calculating machine, the attempts which previously had been made, the requirements for a useful machine, and mathematical proofs for meeting these requirements. Aiken noted, almost with irritation, "[a]t the present time there exist problems beyond our ability to solve, not because of theoretical difficulties, but because of insufficient means of mechanical computation."[10]

Proving His Theories

Aiken claimed that the punched card calculators manufactured by IBM were capable of all the necessary operations that an automatic calculator must perform to meet the needs of science. He outlined the capabilities: it would have to be able to add, subtract, multiply, and divide both positive and negative numbers many digits long, to group and order these operations by using parentheses and brackets; handle both integral and fractional powers of numbers; compute logarithms and antilogarithms in any base; compute trigonometric and antitrigonometric functions, hyperbolic and antihyperbolic functions; and us several trancendental functions such a probability, elliptic, and Bessel functions. Aiken provided ingenious proofs of how all of these complex functions could be reduced to repetitive combinations of the four basic arithmetic operations. He also proved that a simple table of 100 numbers will allow all logarithms to be quickly calculated. Further, he proved that the sign of a number may be represented as a number, and temporary storage areas may be used to hold information while other calculations are proceeding so that paratheses can be used.[11]

Having proved the small number of essential operations needed to perform all scientific calculations, Aiken turned to how an automatic calculator might be constructed. Since the IBM calculating machines of his day could perform the four basic mathematical operations, the problem amounted to expanding their capacity and providing a suitable method of automatically controlling their operation.[12] Although he did not specify the actual construction or operation of the machine, Aiken listed th principle components which it shou contain: a power supply and electric motor for driving the machine; four master control panels, controlled by instructions on punched rolls of paper tape and synchronized with the rest of the machine; manual adjustments for controlling the calculation of functions; 24 sets of switches for entering numerical constants; 2 paper tape readers for entering additional constants; a standard punched card reader; 12 temporary storage units; 5 units each—add/subtract, multiply, divide; various permanent function tables (e.g. sine, cosine, etc.); accumulators; and printing and card punching equipment.[13] All of these components should be built to accommodate figures up to 23-digits long. Finally, Aiken estimated the speed of the calculator based upon the speed of contemporary IBM machines, 750 8-digit multiplications per hour, representing a vast increase in speed and accuracy over manual methods of calculation.[14]

Aiken "visualized [the machine] as a switchboard on which are mounted various pieces of calculating machir apparatus."[15] Although he did not have the specific details of how the various components were to function together, the Mark I was ultimately very similar to the description in his proposal.

(Photo courtesy of Mrs. Mary Aiken)

Convinced of the viability of building an automatic scientific calculator with exisiting technology and with proof in his manuscript, Aiken attempted to find a manufacturer who would build one. He approached many companies in the business of manufacturing mechanical calculators, such as Marchant, Monroe, and National Cash Register, but they expressed no interest.[16] Furthermore, President James Bryant Conant of Harvard warned Aiken that he was risking a tenured position if he continued to pursue implausible schemes.[17] Aiken persevered. Professor Shapley and Theodore H. Brown, Professor of Business Statistics at the Harvard Business School and consulting member of the IBM Department of Education, encouraged Aiken to approach IBM for support. In late 1937, Brown introduced Aiken to J.W.Bryce, "dean of IBM's scientists and inventors."[18] Bryce was receptive to Aiken's proposal and sponsored its passage through the monolithic IBM bureaucracy. Thomas J. Watson agreed to build the automatic calculator and donate it to Harvard, if Aiken would work on the project.[19]

Off and Running

Aiken started by visiting IBM's Columbia University computation facility, where he saw IBM machines being used to perform scientific calculations—but not automatically. This helped him get acquainted with state-of-the-art IBM equipment. A cadre of IBM's top engineers was assigned to the project. The head of the team was C.D. Lake, a true mechanical genius. Under Lake were two other top-flight engineers, Frank E. Hamilton and Benjamin M. Durfee. Aiken and Bryce acted as administrators and overseers, while also taking part in designing of some of the components. These five men formed the central core of the Automatic Sequence Controlled Calculator (ASCC) project.

During the summers of 1938 and 1939, Aiken left Cambridge, where he lived with his wife Louise and daughter Rachael, and spent the season in Endicott working with the IBM engineers. What part he played in the design of the computer is unclear. Given the relatively small amount of time he spent in Endicott, and the large expertise of the other men (Bryce had over 400 patents in his name), he probably had a small hand in the design. However, he did work with Hamilton on the design of the function tables for logs, sines, etc.[20] Many of the components incorporated in the calculator were, in fact, patented under the names of IBM engineers. For example, the multiplying and dividing was patented in 1937 by Bryce and another IBM engineer. Hamilton and Durfee designed the control circuitry.[21] As the project progressed from the theoretical realm of design to the task of fabricating the calculator, Aiken had less direct involvement with it. Aiken later acknowledged IBM engineers Lake, Hamilton, and Durfee as co-inventors of the ASCC.[22]

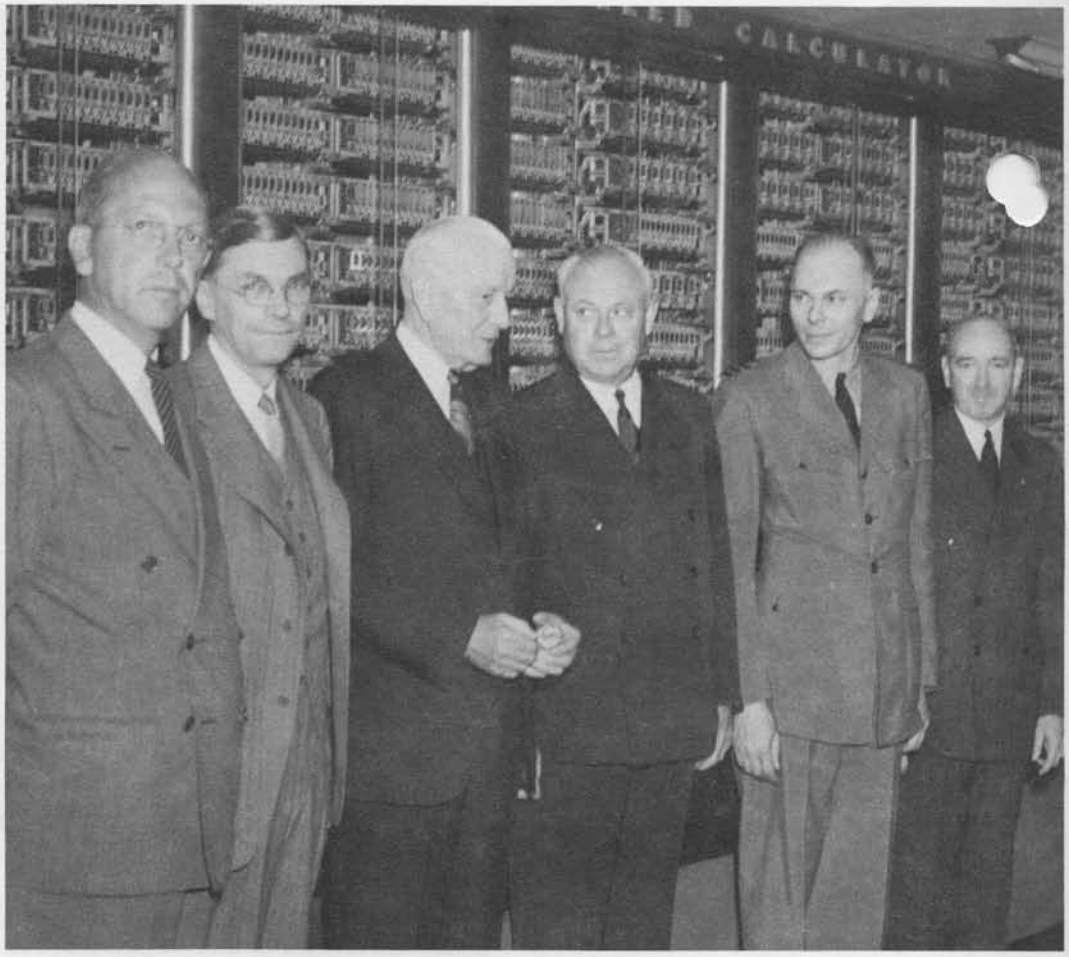
By late 1939 the design process had advanced enough that Aiken's intimate involvement with the project was no longer needed. He received his Ph.D. in June, 1939, and was appointed Faculty Instructor of Physics at Harvard. After the U.S. entered the Second World War, Aiken enlisted in the U.S. Naval Reserve. He was aware of the tremendous help his calculator could be to the war effort, yet the construction had some time to go and Aiken had to wait.

Some time during this anxious period, Aiken met Agnes Montgomery, a young Latin teacher pursuing a Master's Degree in Education at Harvard—a rare phenomenon at that time. "Monty," as she preferred to be called, was quite an extraordinary young woman. The daughter of Scottish immigrants who had become well-to-do, she graduated from Wheaton College and spoke several languages, including French and Russian. She was introduced to Aiken by mutual friends at Harvard. She and Aiken would hop in her Ford Coupe and take picnics into the pastoral countryside surrounding Boston. They would spend hours talking and laughing. Both had an abundant sense of humor. Monty's laugh was high and gay and her flaxen hair and blue eyes shone in the New England sun.

Aiken divorced Louise in 1942.[23] Soon he and Monty were married in a small ceremony at her parents house in Worcester, Massachusetts. By then Aiken was on active duty in the Naval Reserve as a Commander and on a leave of absence from the University. He cut a dashing figure in dress whites, standing ram-rod straight at over six feet tall. The Navy assigned Aiken to teach mathematics at the Naval Mine Warfare School in Yorktown, Virginia. Although he made many friends at the Mine School, he did not relish the assignment.[24]

Wartime Advances

The work on the calculator had progressed far enough that the first problem was run on it in January 1943, but it was not until December of that year that the calculator was demonstrated at Endicott to President Conant.[25] The urgency of the war effort caused things to move quickly. In February, 1944, the ASCC was disassembled at Endicott and shipped to Harvard. Aiken was transferred from the Mine School to Har-



Posing in front of the ASCC at its dedication, August 14, 1944, are (left to right): Frank E. Hamilton (IBM), James Bryant Conant (President of Harvard University), Thomas J. Watson, Sr. (President of IBM), Claire D. Lake (IBM), Howard Hathaway Aiken (Harvard), and Benjamin M. Durfee (IBM). (Photo courtesy of Harvard University)

vard to run the calculator for the Navy. Lake and several other IBM engineers reassembled the machine in the basement of the Research Laboratory of Physics. Meanwhile, Aiken assembled a contingent of Naval personel to operate the Mark I. Among these were Lieutenant Grace M. Hopper, later instrumental in the development of the computing language COBOL, and Ensign Robert V.D. Campbell, who had been the national chess champion in his age-group as a youngster.[26] By May 1944, the calculator was complete and beginning to turn out results for the Navy's Bureau of Ships. Its first project was the computation of tables of values for Bessel functions—a family of mathematical functions crucial to applied physics problems encountered in designing ships.

Friction

Amid great hoopla, IBM formally presented Harvard with the ASCC on August 14, 1944. Whether through a misunderstanding or a conflict in their strong personalities, Watson and Aiken had a falling out over this event which was never repaired. One story has it that Aiken leaked word of the dedication to the press before IBM's media blitz. Consequently, it was Harvard that got most of the publicity, after IBM had spent half a million dollars building the machine. President Conant visited Watson in his hotel room in Boston to cajole him into attending the ceremony. Although Watson put on a happy face for the press, emotions were still very strained. As Thomas J. Watson Jr. later recalled, it was a tense scene in which "[i]f Aiken and my father had had revolvers they would both have been dead."[27] Time did not soothe this wound. Twenty-five years later, at an exhibition on computing history, T.V. Learson, then chairman of IBM, had only one comment to make about the two-thousand years of history spread before him. He paused briefly in front of a photo of Howard Aiken and muttered "the sonofabitch."[28]

Despite the conflict, both Conant and Watson hailed it as the beginning of a new era of cooperation between the two institutions and between science and industry in general. The press marveled at what it called a "giant electric brain." Speculation ran rampant as to how machines such as this might affect the world. Science had overcome its biggest hurdle, they claimed—it had created a thinking machine.

The Shape of the Future

The media fueled the public's imagination. Aiken received letters from people interested in the Mark I and how the new machine would affect them. Many of these letters were from fellow mathematicians and physicists with problems they wished solved, or inquiring where they might acquire such a machine. Many hoped this machine could answer problems long unsolved. They had yet to deal with the economics of information processing. Aiken politely replied that at that time the Mark I was engaged full-time with work for the war effort and could not be spared to solve their interesting problems. Furthermore, there were no machines like the Mark I commercially available. School children wrote asking how they might grow up to build such marvelous machines. One even asked if his laborious calculation of the value of Pi to 28 decimal places was correct. Aiken's replies to these youngsters was one of restrained encouragement. Study mathematics, physics, and electrical engineering first, before designing any machines, he said.

Mathematicians, professional and would-be, were not the only ones to recognize the potential that the Mark I represented. Since the Mark I was automatically controlled, many people anticipated that other kinds of machinery might operate without human intervention. Some saw this possibility as a

on, others as a threat. A printer wrote to Aiken asking about the ramifications of the Mark I for the possibilities of an automatic typesetting system to increase the productivity of his business. On the other hand, a labor union leader expressed concern about the implications for American factory workers of automatically controlled machines. He wished to talk to Aiken about the extent to which "labor-displacing techniques" might be employed at the cost of workers when the War was over.[29] Aiken replied that his time was utterly devoted to the Navy, but the union official might be interested in speaking with Professor Shapley at Harvard or Professor Norbert Wiener at MIT.[30] With astonishing precision, lay people saw many of the long-run implications of the movement of which the Mark I was the vanguard.

Many professionals interested in computing machines wrote to Aiken to complain that the media reports were too sensational and no professional paper had been published describing the machine. Aiken assured these writers that he would publish a thorough report on the computer at the earliest opportunity. In 1946 the Harvard University Press published Volume 1 of the *Annals of the Computation Laboratory of Harvard University, A Manual of Operation for the Automatic Sequence Controlled Calculator*, compiled from the notes of the staff and designers by Aiken and Lt. Hopper.

The manual gave an elaborate description, illustrated with diagrams and photographs, of the physical construction, the electrical circuitry, and the operation and programming of the Mark I. In the foreword, President Conant gave a brief description of the development of the ASCC, and stated: "I cannot refrain from paying tribute to Mr. Watson . . . the scientific world is indebted to him."[31] Conant also stressed the synergistic relationship between science and industry that the ASCC represented. Following Conant's statement is Aiken's preface. Aiken named Lake, Hamilton, and Durfee as co-inventors of the ASCC, and expressed gratitude to the Navy on behalf of the staff for the "privilege of working with the calculator."[32] It had been a mathematician's dream-come-true.

Staggering Dimensions

A Manual . . . provides a detailed description of the physical composition of the Mark I. Over fifty feet long, the Mark I was finished in glass and metallic gray panels in the round, streamlined style characteristic of industrial design in the late 1940's. The machine's physical dimensions were staggering: at eight feet tall, three feet deep, with two, six-feet-long sections projecting off the rear, it weighed 5 tons.[33] This massive frame held 765,299 separate parts, including over 3,000 relays (electric switches), and 225 circuit breakers, connected by 530 miles of wire![34] A four horse-power electric motor drove a shaft extending the length of the machine, which powered all of the mechanical components by gears or chains. The machine performed calculations through a combination of electrical and mechanical processes. Over 1,200 ball bearings kept the components smoothly churning out numbers.[35]

Looking at the machine from the front, one saw on its left end a bank of 1,444 black dials behind sliding glass panels. These were the "constant registers." (A register is a place in which a number is stored in a computer.) There were 60 of these constant registers, each consisting of 24 ten-position dials. Each register held one 23-digit number—one dial per digit—the final dial indicating the number's sign (positive or negative). These switches would be manually set at the beginning of each program according to the equation being solved. Since the value of these registers remained unchanged during the operation of the program they were given the name "constant registers." The sections where numbers produced and changed during calculations were kept were called "storage registers," or "storage counters." There were a total of 72 storage counters, again, each capable of containing a 23-digit number and its sign. The storage counters were made of electro-mechanical "wheels"—24 per counter. Each wheel was mechanically driven by a drive-train system connecting it with the main drive shaft and motor. Depending upon its position, metal brushes mounted on the wheel would complete one of ten possible circuits. Each circuit represented a different decimal digit. To add a number to the number stored in a counter, the wheel was mechanically advanced that number of positions. For example, to add four to the stored number, the wheel advanced four positions. This caused the brushes to complete the circuits representing the sum of the two numbers. The computer automatically carried any overflow to the next digit counter.

While the counter wheels were usually reliable, occasionally deposits would build up on the brush surfaces causing them to complete circuits sporadically. When this happened the procedure was to shut off all the lights in the computer room while the computer was running. Any counter that sparked as electricity arced over the space caused by sediment build-up was replaced, cleaned, and kept as a spare.[36]

One time a problem was caused by a peculiar kind of deposit. On a hot summer day the calculator ceased to function properly. Despite every effort, no explanation could be found for the problem. The only option left was to begin taking apart the machine. The technicians rolled up their sleeves and set to work, carefully pulling out each component and inspecting it thoroughly. In spite of the open windows—in the absence of air conditioning—it was sweltering in the basement of the Physics Labs. Finally, after hours of sweaty work, the technicians found the culprit. A small moth was caught in the contacts of one of the relays, preventing current from flowing through the component. The deceased moth was taped into the logbook above the entry that "a bug had been found in the computer." Soon "bug" became the term for any inexplicable problem and has remained so in computer lingo ever since.[37]

Special Features

Certain of the 72 storage counters had special features. For example, storage counter #70 converted any number placed into it to its absolute value; i.e., it converted its sign to positive. Storage counter #71 was called the "multiple in-out-counter." In effect, it doubled the calculator's storage capacity while halving its accuracy. This was accomplished by treating the contents of counter #71 as two separate 12-digit numbers, rather that a single 23-digit number. Counters 68 and 69, and 64 and 65 accomplished the reverse. They essentially halved the calculator's capacity, but doubled its accuracy. The numbers stored in 68 and 69 were treated as one long 46-digit number; likewise for counters 64 and 65. Two pairs were needed for the purpose of adding two 46-digit numbers together.[38]

While addition and subtraction were performed directly in the storage

Lt. Grace Hopper and the Mark I

Lt. Grace Hopper was assigned by the Navy to work on the Mark I at Harvard in 1944. Two programming ensigns, Robert V. D. Campbell and Richard M. Bloch, were on board when she arrived. Four enlisted men were also assigned to operate the machine, Hugh Livingston, John Mahoney, Donald Calvin, and Derwood White.

She recalls, "They were called specialists 'i'. Their insignia was a diamond with an 'i' in it. The 'i', of course, stood for IBM. Later Yeoman Frank O'Donnell brought order out of chaos and Lt. Arnold and Ensigns Lockhardt and Brennan joined the crew. Civilian members came, but it was a small crew and a very big machine.

"I only know one person who was able to write a program in ink and have it run the first time. That was Dick Bloch. He drove nearly all of us crazy because he could do that. Since the Mark I was a relay and step counter machine, it was not too difficult to change the circuits. Every once in a while, Dick would get the idea of a new circuit that would make his problem run faster. He'd get together with one of the operators during the night and they would "fix" the circuit. The next morning my programs wouldn't run. It's much better to have machines that the programers cannot alter.

"Commander Aiken was a tough taskmaster. I was sitting at my desk one day, and he said, "You're going to write a book." I said, "I can't write a book." He said, "You're in the Navy now." And so I wrote a book. I have it here with me. This is the Mark I manual.

"Howard Aiken always said that one day we would have computers that would fit in a shoe box. I don't know how he knew that, but he did."

Commodore Grace Murray Hopper, speaking at The Computer Museum, April 14, 1983.

counters, multiplication and division were executed in a central unit to the left of the storage counters. The multiply/divide unit was a sophisticated assembly of electrical and mechanical components.[39] When two numbers to be multiplied were received by the unit, it would immediately set up a "table" of the multiples of the multiplicand (the top number in long-hand multiplication) and the nine non-zero decimal digits. Then it would examine the multiplier (the "bottom" number) starting with the units digit. The unit would add together the multiples of the multiplicand corresponding to the values of the digit places of the multiplier. This produced the final product. Division was performed by a method similar to the one above executed in reverse. Often programs would use a function for evaluating reciprocals (based on an algorithm developed by Aiken in 1938) to avoid division.[40] This was done to save time, since at full capacity the calculator could multiply two numbers in 5.7 seconds, while it took 15.3 seconds to perform a division.[41]

Next to the multiply/divide unit were mounted three "interpolators." These units were used to obtain values for certain mathematical functions, such as cosine or hyperbolic sine. The values of a function were encoded on paper tapes prepared for certain values of the variable. (In the case of cosine, this might be the cosine for every half degree between 0 and 90.) Also encoded on the tape were coefficients which allowed the machine to determine the value of the function to the accuracy needed in the problem.[42] The interpolators, large mechanical punched paper tape readers, allowed the calculator to find the value of a function for any variable. This allowed a programmer to use a function in his program simply by loading the appropriate function tape into an interpolator unit, rather than having to write out the algorithm for its calculation, saving a great deal of time for both the programmer and the machine.

The most important component of the ASCC, the automatic sequence unit, was mounted at the right edge of the body of the machine. This unit read the program from punched paper tapes to control the flow of numbers and the performance of operations within the calculator. The paper tape had a three-section line of 24 holes across its width. The pattern of holes in the first two sections indicated the locations of the numbers to be acted upon. This determined the flow of data along the "bus" or large circuit, which connected all sections of the computer. The third section specified what operation was to be performed upon the numbers.[43] The sequencer automatically advanced the tape in synchrony with the internal operations of the calculator. Every line of the program had to include a seven in a specific location to tell the computer to advance to the next line—if there was no seven, the calculator stopped and a bell rang.[44] The Mark I also automatically checked its calculations for errors, if one occurred, it would stop and the bell would ring to notify the operator.

The final three calculating sections of the ASCC were electro-mechanical tables for the calculation of logarithms to base ten, powers of ten, and sines.[45] In addition to the sequencing unit and constant switches, information could be entered into the calculator via two punched card readers. Results of calculations could be punched onto standard IBM punched cards or typed on automatic typewritters.[46]

In addition to describing the mechanical and overall operation of the Mark I, *A Manual . . .* outlined the electrical function and circuitry of the calculator in Chapter Three. The final three chapters dealt with the programming and operation of the calculator. To compliment *A Manual . . .* on this score and further assist the programmer, Aiken and Ensign Robert Campbell (the only person ever to have run a program correctly on the first attempt) compiled a complete code book.[47] The code book elaborated the basic means of programming almost every type of mathematical problem known.[48]

In sum, the Mark I was a vast electro-mechanical calculator which automatically performed decimal arithmetic under programmed control. As the first computer to hit the public with a splash, the Mark I paved the way of the Computer Age.

A New Business for IBM

The public impact is one of the most important influences of the Mark I, but the effect it had upon IBM is also worth noting. The ASCC, IBM's first successful venture in the realm of automatic general-purpose calculators, was built by a team who became influential in the design of many of IBM's later products.

Lake and Durfee went on from the Mark I project to construct the Pluggable Sequence Relay Calculator. Less sophisticated than the Mark I, the various parts of this computer were literally connected by wired plug boards to sequence calculations. However, the use of plug boards and electro-magnetic relays allowed it to run faster than its predecessor.[49] Two of the machines were installed at the Watson Scientific Laboratory at Columbia University. Wallace Eckert, the director of Columbia's Watson Lab, and Frank Hamilton from the ASCC project, then designed the Selective Sequence Electronic Calculator (SSEC). The SSEC was a hybrid machine, composed of both electro-mechanical relays (advocated by Hamilton for their reliability) and electronic vacuum tubes (suggested by Eckert for their speed).[50] Although it was dismantled in 1952, only four years after its widely-publicized dedication, the SSEC was important because members of its design team went on to play crucial roles in the design of some of IBM's first fully-fledged computer systems.[51]

The history of the Mark I's use at Harvard is also very important. Many revolutionary applications were developed for the calculator which broadened the scope of computing at an early stage. During the War, the calculator was used to generate mathematical tables of the values of certain complex functions, such as Bessel functions and Henkel functions. These functions were important in such applied physics problems as ship design, ballistics, and radio wave propagation. Until the Mark I, only a few values of the Bessel function had been calculated since its definition two-hundred years before.[51] The values of these functions were published in volume after volume of the *Annals of the Computation Laboratory*. . . . To insure the accuracy of these tables, they were photographically printed directly from the typed output of the calculator. The Mark I was also rumored to have performed calculations for the Manhattan Project.[52]

Original Applications

After the War, at Aiken's insistence, the Mark I was used on several very original projects. Among these were programs for translating languages, and analyzing econometric models. This latter work, developed by Harvard Professor of Economics Wassily Leontief, simulated the effects of economic currents upon national economies, and eventually led to a Nobel Prize in Economics. Leontief's was the first application of a computer to a problem in the social sciences. Aiken also urged a friend to perform his research on Newton's *Principia* on the computer.[53] In 1947 and 1949, the Harvard Computation Laboratories sponsored two symposia on "Large-scale Digital Calculating Machines." High on the agenda of both these conferences were discussions of new applications of computers, particularly in unconventional fields such as physiology.

The emphasis placed upon finding new applications for computers was an extension of the motive which drove Aiken to pursue the construction of an automatic calculator in the first place. "You see," Aiken said, "I used to have a lot of figuring to do and I thought it would be nice to have a machine that would make my job easier."[54] Aiken's true concerns were the results which computers could help achieve. He ventured to produce a computer only because one could not be acquired elsewhere. Later, when a commercial computer industry had developed, Aiken ceased constructing computers in favor of concentrating on research in their application and basic design. He built a curriculum at Harvard in Applied Mathematics with specific concentration on computing machinery, and advocated international cooperation in the field of computing.

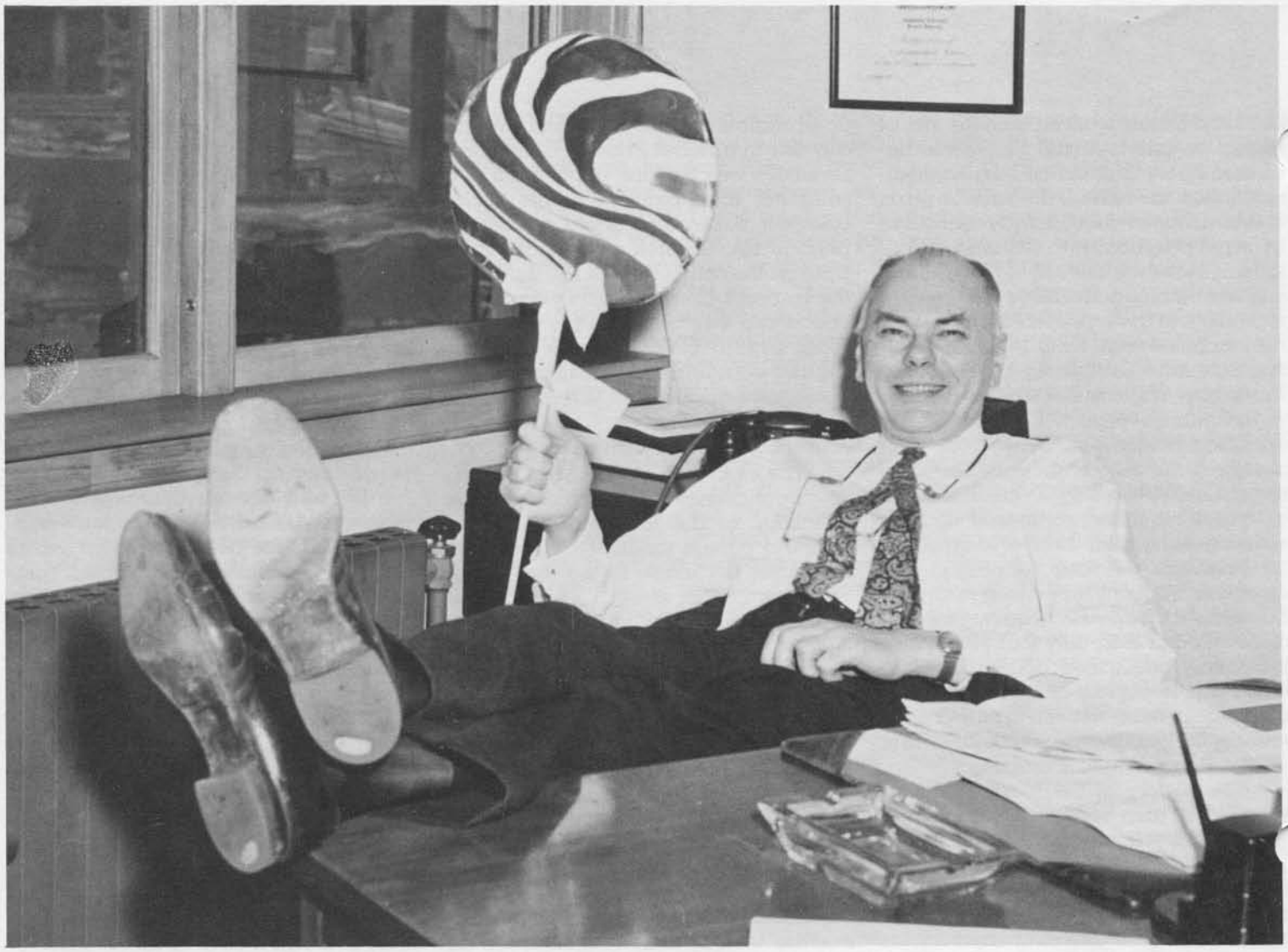
The Birth of the Lab

At the end of World War II, Aiken completed his Naval service and rejoined the Harvard faculty as a Professor of Applied Mathematics. He was appointed director of the Harvard Computation Laboratory when it became indepedent of the Navy at the end of the Bureau of Ships contract. Aiken worked assiduously to build the staff and facilities of the Computation Lab and encourage its use throughout the University. In addition to teaching, working on the design of Mark I's successors, consulting, and traveling across the globe, Aiken arranged the financing and construction of a building to house the Computation Laboratory. The building was dedicated in 1947 at 33 Oxford Street, just north of Harvard's physics buildings. Financed primarily by government funds (many of them from the rental of the Mark I), the two-story brick building contained office space, lecture halls, a machine shop, and a sixty-foot-square room for the installation of computers. The computer room had a large observation window for visitors. The Mark I was moved from its basement location to the modern brick building in late 1946. Upon its dedication, Harvard officials referred to the Lab as the first building of a "Science City" which would house facilities for all of the varied fields of natural science in one massive complex.[55] The first building of a centralized science complex seemed an appropriate place for a facility which, as Aiken saw it, would serve all disciplines.

With the construction of proper facilities completed, Aiken saw the immediate mission of the Computation Lab as two-fold: to build a large modern computer for use exclusively by the University, and to develop techniques and a curriculum of mathematical analysis so that the use of computers might spread throughout all fields.[56]

At the end of World War II, the Bureau of Ships contract for the operation of the Mark I expired. To finance the operation of the calculator, Harvard entered into a contract with the Navy's Bureau of Ordnance. The Bureau of Ordnance paid the operating costs of the Computation Laboratory in exchange for having ballistics calculations performed on the Mark I. Unfortunately, the Bureau's projects took up most of the calculator's time, leaving little for academic research. In 1945 the Bureau of Ordnance had contracted Harvard to construct a large relay computer to be installed at the Naval Proving Grounds in Dahlgren, Virginia.[57] This contract included the operation of the Mark I until the second calculator was completed. The Mark II, finished in March 1947, was shipped in 20 trailor trucks to the Naval Proving Grounds. The largest computer in existence, it contained over 13,000 relays and was employed in the solution of complex ballisitics problems.[58] The completion of Mark II signalled the end of the Bureau of Ordnance's support of the Mark I. To keep the Mark I operating, the Laboratory entered into several contracts with the Air Force and the Atomic Energy Commission. Under these contracts academic computing suffered as it had under the Bureau of Ordnance's support.

Even before the Mark II was completed, the Bureau of Ordnance extended its contract to include the construction of a further computer, the Mark



III, for installation at the Navy's Aberdeen Proving Grounds. The Mark III used vacuum tubes to perform calculations; as a result it was 250 times faster than the Mark I, and 25 times faster than the Mark II. The Mark III also incorporated a magnetic drum memory with a capacity of 64,000 digits.[59]

By this time Aiken emphasized that Mark I would not be able to satisfy the computation needs of the University. Therefore, he advocated the construction of a larger calculator to serve the needs of academic research at Harvard. To complete the computer as expeditiously as possible, Aiken recommended that the Mark IV, as it was to be called, be very similar to the Mark III. Once again, however, Aiken ran into financing problems. In order to build the computer, he had to rent time on it to government agencies and private industries. When the Mark IV was complete in 1952, it was installed opposite its great-great-grandfather, the Mark I, in the Computation Laboratory.

While the effort to provide the University with a sizable computer came to only partial fruition, the second goal of establishing a curriculum in computing was achieved with the military's help. In 1947 the Office of Naval Research sponsored a one-year Master's of Science program in the field of computing machinery. The following year, the Air Force took over responsibility for the program. By 1949 76 students had enrolled in the program, and 14 M.S. and 1 Ph.D. had been granted.[60] Aiken was instrumental in sponsoring and developing the curriculum for this program. In 1955, Harvard announced the introduction of a complete Master's and Doctoral program in Applied Mathematics focussing on the problem of automatic control. It was one the first universities to offer such a program.[61]

The Boss

With its two primary objectives somewhat satisfied and private industry ready to take on the construction of computers, the Computation Laboratory became a major center for research in computer design and theories of mathematical computation. One of the only institutions of its kind, it attracted many promising students and teachers. Visitors came from all over the globe. The Lab was a diversified and stimulating community, over which Aiken held unchallenged sway. "The Boss," or "the Old Man," as his students referred to him among themselves (he was always Professor Aiken in person) was remembered as an inspiring teacher, who had a way of driving people to achieve things they thought they could not possible do. Although he was not the chummy sort, (he always maintained the formal relationship of teacher versus student) Aiken was very accessible despite his frantic schedule.[62]

The Lab was characterized by pride and perfectionism. With two computers operating round-the-clock, courses to be planned, and many pioneer research projects underway, lights blazed all night in the computer room and the offices downstairs. "The Boss" was likely to show up at any hour, including four in the morning, to ask if the computer was "making numbers" (i.e. running smoothly), or to try some new idea.

(Photo courtesy of Mrs. Mary Aiken)

kitchen was set up off the side of the computer room for those working the late shifts. When an error occurred during the running of a program, the Mark I would stop and a bell would sound. Often the operator would find that Aiken had beaten him to the side of the machine. Aiken would stand rocking forward and backward on the soles of his patent leather shoes, hands fidgeting in his front pockets. "Well, what are you going to do about it?," he would prod. If the calculator had not soon resumed operating, Aiken would take off his jacket and set to work with the operator to solve the problem. This near obsessive drive to keep everything running like clockwork made Aiken the butt of good-natured kidding and practical jokes.

One day Aiken arrived at the Lab and, as always, went directly to the chart which indicated the status of the calculator. Instead of a blue line, indicating error-free operation, there was a solid red line, showing the computer had not been operating all night long. "What the hell is going on here?," he burst out at the operator on duty. "Where's Hawkins [the Chief Operator]?"

"Downstairs." Off Aiken stormed on seven-foot strides. When he found the Chief Operator, he growled, "What the hell are you doing here reading the paper? Why aren't you upstairs? The goddamn machine's been broken for thirteen hours."

"You're crazy. The machine ran all night long," responded the Chief Operator.

"Well the goddamn chart is red," Aiken thundered as he strode back upstairs. He returned to find the operator removing a strip of red tape which had been covering the blue line on the chart. "Well, I guess I've been had," he grinned. When the operators recovered from their laughter, they presented Aiken with a large red badge which he sported the rest of the day.[63]

Aiken had a combination of a dry, teasing wit, and the ability to laugh at himself. His secretary recalled that on her first day she spilled a pile of books in the middle of the hall. "It's about time you picked those up," Aiken said flatly ... with a small smile as he ushered some visiting Navy brass around the prostrate woman.[64]

Aiken's firmness, drive, and humor made him a good leader for an eager and brilliant staff. Most who worked with him speak of Aiken in the fondest and most admiring of terms. Yet a comment that Aiken made to a student once betrays the attitude which earned him the emnity of some, and caused him to become disillusioned in later years: "Don't worry about people stealing your idea," he said. "If it's original you will have to ram it down their throats."[65] This attitude represented what his critics claimed was Aiken's condescending and superior air.

After the War, Aiken traveled widely assessing computing progress across the globe. Convinced of the value of the results of calculations to all people, Aiken pushed for the establishment of an International Computing Laboratory under the auspices of the United Nations. These aspirations proved politically unfeasible, and Aiken later wrote to a friend that the complications of an international bureaucracy proved insurmountable.[66]

Aiken attacked bureaucratic red tape with the vigor that characterized all his work. For example, his lobby efforts to allow Harvard to operate radio transmitters without a government-licensed operator eventually led to legislation making communication satellites possible.[67] The reluctance of Harvard to fund the development of proper computing facilities greatly hindered Aiken's efforts. University policy also forbade him to do any classified government work. This made supporting the computers all the more difficult. It is understandable that Harvard had trouble justifying the great expense of a facility which fell under the domain of no department, and was difficult to think of as a utility like electricity of heat. As a result, the administration's attitude seemed to be "you want it, you fund it."[68] This Aiken did, by charging for computer time, private contracts, and soliciting donations. He arranged the contribution of a UNIVAC 1 computer system during the mid-1950's. A tumultuous conflict surrounding the purchase of an IBM 7090 computer system proved to be the final straw. Aiken retired from Harvard at the minimum age in 1961, to avoid falling "into the trap which has caught so many of my senior colleagues."[69]

Life After Harvard

The desire to start a new life and learn new things at age 61 applied to his private affairs as well as his career. He divorced Monty and soon married Mary MacFarland of Coral Gables, Florida.

His activities increased upon retirement. In 1963 he formed his own company, Howard Aiken Industries, Inc.[70] He also accepted positions on the board of directors and consulting staff of several firms. In addition, he held a distinguished service professorship at the University of Miami. While there he designed and established a computing center with the aid of the local Chamber of Commerce.

Aiken soon moved to Florida, where he lived with his new wife and his two step-daughters. During their rare moments of relaxation together, they enjoyed walking along the beach, swimming, and listening to music. On the whole, however, Aiken had little time for recreation, relaxing while en route to airports.[71] While on business in Missouri, Howard Hathaway Aiken died on March 14, 1973—six days after his seventy-third birthday.

At a memorial service in his honor in Memorial Church at Harvard, friends and colleagues gathered to remember the life and accomplishments of Howard Aiken. The range of tributes attest to the diversity of his life. Students remembered him as a great teacher, others remembered him as a great Naval officer, and scientist—all remembered him as a proud and kind man. A former employee later wrote, he was "the only completely moral man I ever knew."[72]

Aiken's work and achievements earned him wide recognition in Europe and the United States. He received many honorary degrees and awards from all over the world. In acknowledgement of his contributions, Harvard University named the computer laboratory the Howard Hathaway Aiken Computation Laboratory in 1964.

His wife, Mary, described Aiken's life best when she wrote: "It was certainly a colorful, inventive, stormy, and changing life. He came into the world and left it in a fast clean-cut way."[73]

Endnotes

Special thanks to Professors Thomas Cheatum and Anthony Oettinger of Harvard University.

Abbreviations
HUA—Harvard University Archives, Harvard University, Cambridge, Massachusetts.
AOF—Active files of Dr. Anthony Oettinger, Chairman, Program on Information Resources Policy, Harvard University, Aiken Computation Laboratories, 33 Oxford Street, Cambridge, Massachusetts.

[1]H.H.Aiken, "Memorandum on the Computation Laboratory," (Cambridge, MA, October 19, 1949), Computation Laboratory Collection, HUA, p. 1.

[2]"Howard Hathaway Aiken A Giant Among Us in Computer Design," *Harvard University Gazette*, vol. LXIX: no. 37, p. 8.

[3]Howard H. Aiken to Dr. Warren Weaver, September, 5, 1940, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: A–C, Folder: "Correspondence Before '44," HUA.

[4]ibid. The dates indicated in this letter differ from those of Aiken's Curriculum Vita. I have chosen to regard the letter as the accurate source. The letter was composed by Aiken himself, while the c.v. might have been drawn up by a secretary. Furthermore, the letter was composed nearer the dates in question. (The copy of the c.v. I have seen was compiled in 1961.) The c.v. indicates the dates of Aiken's early employment as follows:
Madison Gas and Electric Company, 1919 to 1928,
Western Electric and Manufacturing Company, 1928 to 1931,
Line Material Company, 1931 to 1932.

[5]Howard H. Aiken to Rowland Stokes, August, 30, 1944, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: A–C, Folder: "Bureau of Ordnance," HUA.

[6]"Howard Hathaway Aiken A Giant Among Us . . . ," p. 8.

[7]"IBM Automatic Sequence Controlled Calculator," International Business Machines, 1945, Aiken Files, Folder: "Marks," AOF, p. 2.

[8]Anthony Hyman, *Charles Babbage, Pioneer of the Computer*, (Princeton, N.J.: Princeton University Press, 1982), p. 130.

[9]Brian Randell, *The Origins of Digital Computers*, (New York: Springer-Verlag, 1982), p. 204.

[10]"Proposed Automatic Calculating Machine," Computation Laboratory Collection, "Personal Files of Howard Aiken," HUA, p. 5.

[11]ibid., pp. 7–18.

[12]ibid., p. 18.

[13]ibid., pp. 19–21.

[14]ibid., p. 21.

[15]ibid., p. 18.

[16]"Howard Hathaway Aiken A Giant Among Us . . . ," p. 8.

[17]ibid.

[18]"IBM Automatic Sequence Controlled Calculator," p. 2.

[19]Harry Mimno, "Notes by Harry Mimno," Aiken Files, AOF, p. 6.

[20]"IBM Automatic Sequence Controlled Calculator," pp. 2–3.

[21]ibid., p. 3.

[22]*A Manual of Operation for the Automatic Sequence Controlled Calculator*, Annals of the Computation Laboratory of Harvard University, vol 1, (Cambridge, MA: Harvard University Press, 1946), Introduction.

[23]"Co-inventor of Harvard 'Brain' Needs it for His Own Dilemma," Howard H. Aiken Biography File, HUA.

[24]Howard H. Aiken to E.S. Gilletti, November, 28, 1944, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: A–C, Folder: "Bureau of Ordnance," HUA.

[25]"IBM Automatic Sequence Controlled Calculator," p. 3.

[26]Interview with Robert Burns, Manager, Harvard University Parking Office, 29 Garden Street, Cambridge, Massachusetts, November 28, 1984. Burns, an operator of the Mark I, recalled this fact in a conversation on November 28, 1984.

[27]Katherine Davis Fishman, *The Computer Establishment*, (New York: Harper and Row, Publishers, 1981), p. 36.

[28]ibid., p. 37.

[29]Ted E. Silvey to Howard H. Aiken, November, 25, 1944, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: A–C, File: "Bureau of Ordnance," HUA.

[30]Howard H. Aiken to Ted E. Silvey, December, 5, 1944, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box A–C, File: "Bureau of Ordnance," HUA. Norbert Weiner was one of the first to envision many of the consequences of the broad use of computer-controlled machinery, a phenomenon he called, "cybernation."

[31]*A Manual of Operation . . . ,* Foreword.

[32]ibid., Preface.

[33]*A Manual of Operation . . . ,* p. 11.

[34]"IBM Automatic Sequence Controlled Calculator," p. 6.

[35]*A Manual of Operation . . . ,* p. 58.

[36]Interview with Robert Burns, November, 28, 1984.

[37]Grace Hopper, "Howard Aiken and the Harvard Mark I," Lecture Collection of The Computer Museum, Boston, Ma.

[38]*A Manual of Operation . . . ,* p. 17.

[39]"IBM Automatic Sequence Controlled Calculator," p. 5.

[40]*A Manual of Operation . . . ,* p. 27.

[41]"IBM Automatic Sequence Controlled Calculator," p. 6.

[42]ibid., p. 5.

[43]*A Manual of Operation . . . ,* p. 11.

[44]ibid., p. 15.

[45]ibid., p. 11.

[46]ibid.

[47]Interview with Robert Burns, November 28, 1984.

[48]"IBM Automatic Sequence Controlled Calculator," p. 6.

[49]Randell, p. 192.

[50]ibid., p. 193.

[51]"New Faster Mechanical Brain Being Built At Harvard for Navy," Computation Laboratory Collection, "Clippings, Etc.," HUA.

[52]Interview with Robert Burns, November, 28, 1984.

[53]I.B.Cohen to Kenneth Iverson, April, 23, 1981, Aiken Files, AOF.

[54]"Says Era of Mechanical Calculators Lies Ahead of Us," *Boston Sunday Post*, December 28, 1947, p. 4.

[55]"Harvard Puts Big Calculator in New Home," *The Christian Science Monitor*, December, 30, 1946.

[56]H.H.Aiken, "Memorandum on the Computation Laboratory," p. 8.

[57]Randell, p. 192.

[58]"New Faster Mechanical Brain Being Built at Harvard for Navy."

[59]"The Thinking Machine," *Time*, vol. LV: no. 4, January 23, 1950, p. 54.

[60]Aiken, "Memorandum on the Computation Laboratory," pp. 1–3.

[61]R.L.Ashenhurst, "Remark Prepared for Memorial Service," May 7, 1973, Aiken Files, Folder: "Harry Mimno," AOF, p. 2.

[62]Kenneth E. Iverson, "Howard Aiken, Friend and Mentor," April, 1973, Aiken Files, Folder: "Harry Mimno," AOF.

[63]Interview with Robert Burns, November 28, 1984.

[64]Jacquelin Sanborn Sill, "A Non-Academic Tribute to Howard Aiken," Manchester, Massachusetts, March 1973, Aiken Files, Folder: "Harry Mimno," AOF, p. 2.

[65]Iverson.

[66]Howard H. Aiken to Dr. John Womersky, September, 23, 1952, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: C–I, Folder: "England Dead File," HUA.

[67]Harry Mimno, pp. 2–4.

[68]Interview with Harvey Brooks, Benjamin Peirce Professor of Technology and Public Policy, Harvard University, Division of Applied Sciences, Aiken Computation Laboratory, 33 Oxford Street, Cambridge, Massachusetts.

[69]Howard H. Aiken to Dr. John C. Baker, October 31, 1961, Computation Laboratory Collection, "Correspondence of Howard H. Aiken, Director, 1944–1961," Box: A–C, Folder: "Bureau of Ordnance," HUA.

[70]"Biography of Howard Hathaway Aiken," Aiken Files, AOF, p. 3.

[71]ibid., p. 4.

[72]Martin E. Flaherty to David A. Harnett, October 14, 1974, Aiken Files, Folder: "Harry Mimno File," AOF.

[73]Mary E. Aiken to David A. Harnett, November 19, 1974, Aiken Files, AOF.

Howard Aiken looks over some newspaper clippings in the lounge of the Computation Laboratory. (Photo courtesy of Harvard University)

A Conversation with The Hackers

The following is transcribed from the December 16, 1984 program at The Computer Museum, "A Conversation with Steven Levy and the Hackers." The Museum invited the cast of characters from the book, HACKERS: Heroes of the Computer Revolution *(Doubleday Press, November, 1984), and its author, Steven Levy, to stage a reunion of the original MIT hackers from the 1950's and 1960's. These are the visionaries whose obsessive games-playing, inventive programming, and anti-authoritarian ethic fueled the computer revolution.*

The Cast of Characters

Steven Levy
and
Alan Kotok—like a God, he understands hardware; a legendary hacker.
Steve "Slug" Russell—best known for developing SpaceWar; never made a dime from it.
Tom Knight—arrived at MIT at age 16; a member of the second generation at the A.I. lab.
Mike Beeler—involved with the program called LIFE.
John McKenzie—watched over the hackers on the TX-0 and the PDP-1, and looked out for the hardware—especially the hardware.
Don Eastlake—member of the midnight computer wiring society.
Marvin Minsky—professor of the A.I. lab.
Gordon Bell—a hardware hacker.
Tom Eggers—a hacker "drop out" from MIT.
Richard Stallman—the last of the hackers.

Steve Levy: After the publication of the book, I did a lot of radio interviews and usually the first question anyone asks is, "How could you call those people heroes? These are kids who break into things all the time?" In reply, I had to patiently explain that at one time hacker meant something else. It was a badge of honor among people implying either wizardry or elegance in using the computer. The early MIT hackers did some things with computers that eventually enriched our lives.

How do you feel about the current view of hackers, especially the malicious view?

Alan Kotok: The use of the term faded in the seventies and re-emerged in a new context and was a new word. There was no common line or heritage between the two, but maybe there is a line between the two.

Tom Knight: I still think of myself as striving for the same kind of excitement that a hacker has, but I have less and less time.

Steve Levy: Are hackers born or made? Some people at the hackers conference in California suggested that hackers are born, like baby ducks—when they see something moving, they will follow it, like a hacker has to do.

Mike: As a kid I used to play with plugs and wires, thus scaring my parents. Everyone that has some experience hacking has played with hardware when they were small.

Tom Knight: You need to have a predisposition to either constructing things or logic. Now, of course, there are hackers that are purely software so might not have had to have the same childhood experience. When I was growing up, there just weren't computers, so I hacked organic chemistry for a while. Electronics was one of the only outlets. There wasn't anything else.

Alan: Model railroads.

Steve Russell: And relays. A very elaborate model railroad—that is a parallel.

Steve Levy: Since the anti-social hacker is a myth, how much did the community that evolved around hacking keep you going?

Steve Russell: Hackers were very exclusive and some people may say that their behavior is "anti-social" or not very social. There were few hackers who were reluctant to talk when the right person came along or the right subject came up.

Alan: It wasn't an isolationist type hacking in the old days. No one was in their bedroom, independent of the rest of the world. There was an "in crowd" and some rites of passage into the crowd. The atmosphere was intense among the people involved. You needed someone to talk to about ideas. There were always large crowds going out to dinner together.

Tom Knight: The lack of computers during that era and the fact that there was no timesharing led to more interaction between the hackers in the early sixties than between similar people today. Today you can go to RadioShack or ComputerLand and buy computers that are more powerful than those available in the sixties—and then you can go into your closet and hole up and not talk to the rest of the world. In the sixties you were very visible when you were on a machine.

Steve: The person who wanted to be on next was over your shoulder.

Tom Knight: Yes, and they had very strong opinions about your project and its worthwhileness. This led to a close bond between those people.

Steve Levy: Were the rules strictly adhered to?

Steve Russell: The PDP-1 and other early computers had a sign up list and you could sign up for an hour in advance, and there were rules for parcelling this out. When your time was up, you had about 5 minutes of leeway and the pressure increased, especially because the next person usually showed up early. So you got about 10 minutes of design review after your had finished your work.

Tom Eggers: There was always a fight for the extra hour of computing when we went off daylight savings time.

Tom Knight: The machines ran 24 hours a day. Seven a.m. was quite good, as it was a change between night and day phase.

Mike Beeler: Night phase started with a large dinner, followed by working through the night.

Steve Levy: What was it that made you work so hard and forget about going to class? Many hackers from that era didn't bother to get a degree.

Alan: I didn't suffer from that problem because I wouldn't get next year's stipend. A lot of pressure from my Jewish mother.

Steve Russell: The phenomena of discovering computers and flunking out is no different from the people who discover drama clubs, music, model railroads, or other manias.

Steve Levy: That's the marching band excuse. When I did my first article on hackers, I thought it was different.

Marvin Minsky: Students knew more than their professors about computers.

Gordon Bell: People are obsessed with hardware/software machines because they are animate objects that are extremely complex and often a new unexplored territory of problems. You could tell a good hack. When I taught programming, I'd look at the code and often say to the student, "Do the world a favor. Make sure that you don't write anymore programs." Hackers understood elegance and lived for the creation of machines.

Tom Knight: I think a number of things were happening then that aren't happening now, namely, getting the computer to do things for the first time—to present a Minskytron or a Spacewar or whatever. Further, hacking was the only way to learn computing. Today you can take a course—they're not great.

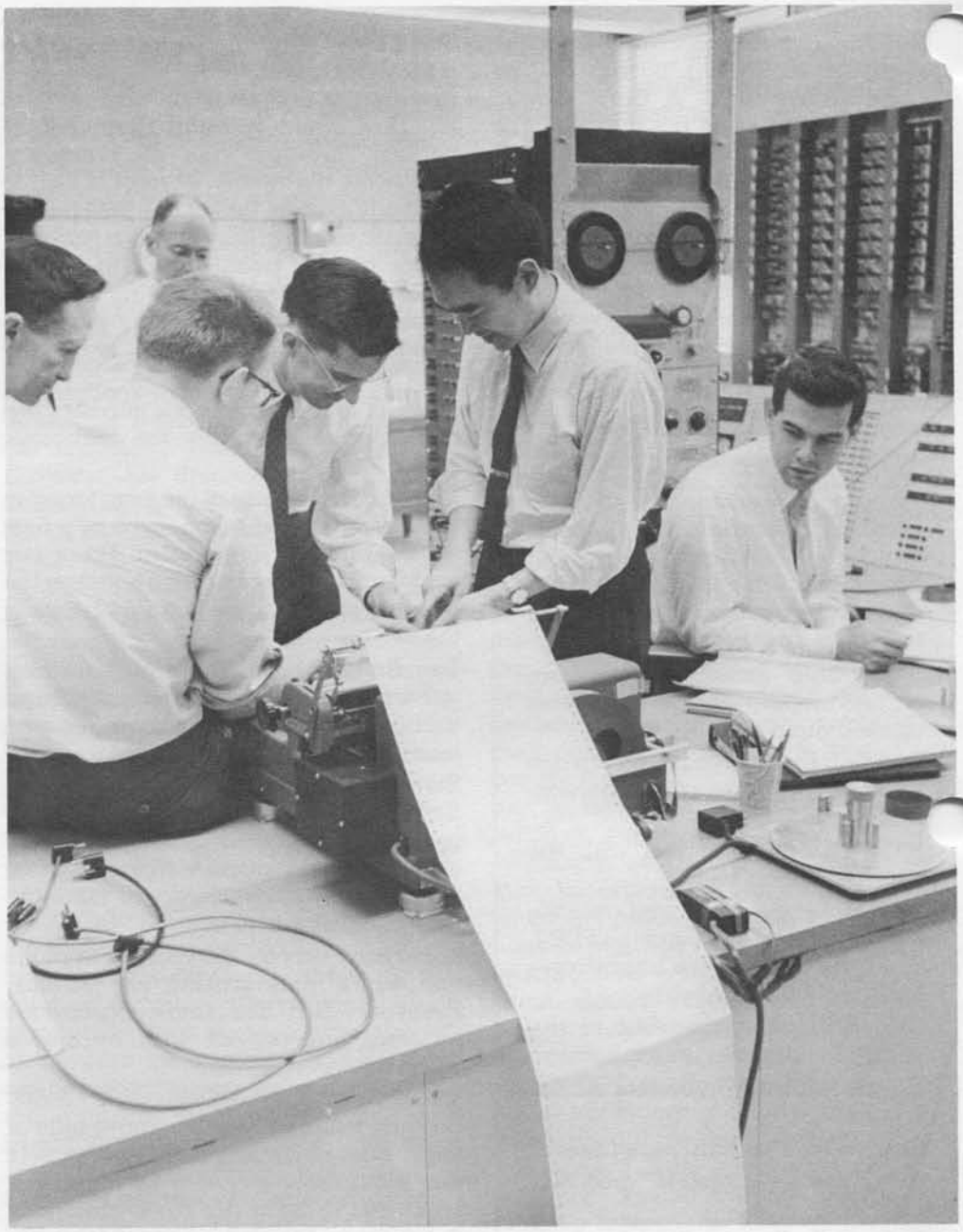
Mike Beeler: The newness today is different. In the sixties we were isolated; today large numbers of isolated people are working on the same problem with the same tools. A new compiler, a new adventure game, and a new Pascal—all on personal computers, nothing on a mainframe. Today repackagers of the hackers' programs can make a bundle of money off it; I don't like the ego investment of doing something for others profit. In the old hacking sense the ideas were "free".

Steve Levy: Richard Stallman, the last of the hackers, wants to say something.

Richard Stallman: You can do what I do: copyright the material, distribute it, and don't let anyone else sell it. Then everyone puts their efforts into the common pool.

Gordon Bell: Are all the EMACS (a text editor) yours?

Richard Stallman: No. There are two EMACS companies, but I think I may put them out of business. These are not my programs, but imitations of them. I think they are wrong, not because copying me is wrong, but because it is wrong to hoard programs. They are not hurting me; they are hurting everyone. I've been



At work on the TX-0 at MIT in the 1960's (left to right): John McKenzie, Gordon Bell, Arthur House (in background), Ken Stevens, Hiroya Fujisaki, Peter Brady. (Photo courtesy of The MIT Museum)

working on an EMACS that will run on NIX and I'm going to give it away free so that the market for the costly programs will dry up.

Steve Levy: In the sixties, people weren't paying for programs. A program as innovative as SpaceWar today would be worth seven figures, but it was a free commodity at the time.

John McKenzie: In 1975, lawyers came into MIT and asked me about SpaceWar. They asked if I could prove it. In the meantime I found the PDP-1 log book that held comments about the winners and losers of the game. The end result was a deposition for a hearing with two lawyers from Bally and two from Magnavox (who was trying to tie it up); in addition, lawyers from Atari and Sanders sat in. It took three days, including explaining the schematic drawings of the PDP-1. That was settled out of court. The sequel of this story is that this year, the lawyers are around again on the same subject with the same principals.

Alan Kotok: They're coming to see me next week.

Tom Eggers: By virtue of dropping out of MIT while hacking on the PDP-1, writing DDT all hours of the day and night, my choice was working for DEC or the Army. Gordon told me I could have a job but I had to finish MIT. I said, I can't. He paid me $500 for DDT I'd written so far.

Alan Kotok: Probably one of the first programs sold.

Tom Eggers: I had never heard about selling programs, but when I had a chance for the money so that I could pay off MIT for the term that I never took, I just took the money. The issue of ethics never crossed my mind.

Richard Stallman: Did that become the DDT used at the AI lab?

Tom Eggers: Yes.

Richard Stallman: Although DEC may have paid you $500, it didn't become a hoarded program.

Tom Eggers: It was distributed with the PDP-6.

Tom Knight: In those days, the manufacturers delivered all the software that existed.

Steve Russell: There was no market for software. No one that had a computer paid any money for software.

Steve Levy: After Slug finished SpaceWar, it was used, copied, and improved over and over. There was no such thought as copyright.

Marvin Minsky: Eventually, SpaceWar was banned for daytime use.

Steve Russell: They put up rules for playing SpaceWar. The rules included that playing the game was lower priority than making new versions.

Tom Knight: In the early seventies, Jim Pitts at Stanford bought a PDP-11 and decided to commercialize SpaceWar. He installed it as a game in one of the Stanford sandwich shops and promptly lost lots of money. This is an example of trying hard to market something and failing miserably.

Steve Russell: Cinematronics on the Westcoast marketted SpaceWar, Asteriods and several derivations with a standard four button control. The only remarkable feature is "viscous space," so that you can slow down by stopping to accelerate, not realistic but interesting for the players.

Alan Kotok: While it only took a couple of people to get SpaceWar going, think of the number of lawyers who have been deployed on the job. No wonder that we have to graduate more lawyers than engineers.

Steve Levy: One criticism is that there were no efforts to get the world at large involved with what the hackers were doing.

Tom Knight: The computers cost a million dollars—and how could you excite the public about something like that.

Marvin Minsky: At the time we started the artificial intelligence lab most people didn't believe that it could exist. People didn't believe that machines could play chess, even after they had beaten people thoroughly. This drew the A.I. people together as a circle facing the world. It took many years to convince industry to adopt timesharing. Generally people don't adopt new ideas, that's the way it is in civilization.

Steve Levy: I heard that even the hackers resisted timesharing.

John McKenzie: They certainly resisted video screens, believing that everything had to be done in hardcopy.

Marvin Minsky: And they certainly resisted lower case.

Tom Eggers: Hackers were elitist. The word "user" was often alliterated to "loser". If you weren't a hacker and couldn't "hack," then you were on the outside.

Steve Levy: The West Coast group that started the drive to personal computers thought of the A.I. labs as elitist. People who didn't care if computers were used. In fact, the computer people didn't even think that the Altair or the Apple I were computers that would lead anywhere and so were ignored. Is this accurate?

Tom Knight: A very accurate perception.

Marvin Minsky: The problem they were working on was how to put bigger programs into 8K machines. At that time, AI was working beyond the 64K barrier and this was what was interesting to the community.

Tom Knight: I remember working in the LOGO lab and discussing whether we should write one for the Apple. We said, "No, it's really too small." We saw it was twice as big as the largest memory for the Apple. But we didn't see that if we spent a year writing the program, then the Apple would be large enough.

Marvin Minsky: We finally got a LOGO into 1K, but it was hard.

Alan Kotok: Two thoughts about memory size: the power supply computer for the latest VAX is probably more powerful than the TX-0; the memory of the system, 32 mbytes, was larger than the entire memory of all the computers in the world when I started.

Steve Levy: Because hackers had disregard for the rules, will the examples provide a bad example?

Alan Kotok: If motivated people who will build great things have to break a few locks, that's the price.

Gordon Bell: There's a difference between fundamental thievery and needing a component in the middle of the night and finding an interesting way to get it.

Steve Russell: Elegance is getting done what you want to do without exciting or interesting the people who might catch you.

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Osborne & Osborne—Adam Osborne poses with the Osborne I (to left) in the PC Gallery at the Museum following his talk on March 3, 1985. (Photo: Peter Cassidy)

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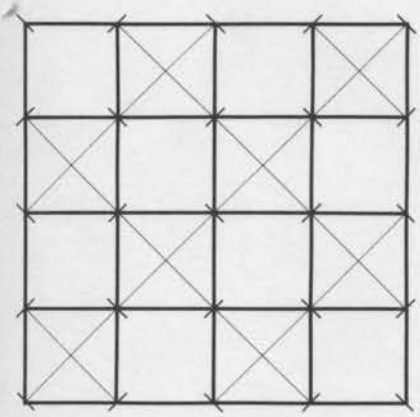

Thursday, May 2—7 p.m.
Dr. Koji Kobayashi, Chairman, NEC Corporation
The Development of the Japanese Computer Industry

Thursday, May 16—7 p.m.
COBOL's 25th Anniversary: The Story of the COBOL Tombstone
CODASYL members John L. Jones, Commodore Grace M. Hopper, Thomas Rice, Oliver Smoot, Jan Prokop and Donald Nelson will tell the story of COBOL's development and those who thought that a machine universal language would never survive.

Sunday, May 19—4 p.m.
The Human Factor: Designing Computer Systems for People
Why are some computer systems such a pleasure to use, while others are not? Authors Dick Rubinstein and Harry Hersh will show that the design of good human/computer interfaces isn't a black art.

Sunday, June 2—4 p.m.
A Museum Overview with Maurice Wilkes
Mr. Wilkes developed the EDSAC, the first stored program computer, and has played a role in many other advancements in computer technology. He will talk about many of the computers exhibited in the Museum. His memoirs will be published by MIT Press in June. A Members Reception will follow the talk.

The Computer Museum Attic Sale and Antique Show

Get your hands on computer gadgetry, antique calculating devises, mathematical instruments, photos, graphics, books, manuals, and more at the Museum's "computer flea market"—a real hacker's dream.

Saturday, September 21 **6 pm**	Benefit Preview Party and "Private Sale" $20 members; $30 non-members
Sunday, September 22 **11–6 pm**	Attic Sale and Antique Show 4 PM—Panel discussion on "computer collectibles"

Clean out *your* attic with contributions for the Museum—fully tax deductible. One hacker's throwaways are another's key parts, so mark your calendars!

Also, vendor tables will be available for rent. Please call Majie Zeller for more information, (617) 426-2800 ext. 339.

THE END BIT 0000000001

Cambridge, Mass., February 25—The Air Force announced today that it has a machine that can receive instructions in English, figure out how to make what is wanted, and teach other machines how to make it.

An Air Force general said it will enable the United States to "build a war machine that nobody would want to tackle."

Today it made an ashtray.
—*San Francisco Chronicle*

In a sulk, probably.

—*The New Yorker Magazine* of March 28, 1959 on the first object to be designed by computer and manufactured directly from the computer output.

The ashtray was donated to The Computer Museum by Douglas T. Ross and is on display in the Timeline.

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