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Highlights from
Digital Computer Museum Report 1/1982

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The Digital Computer Museum is an independent, non-profit, charitable foundation. It is the world's only institution dedicated to the industry-wide preservation of information processing devices and documentation. It interprets computer history through exhibits, publications, videotapes, lectures, educational programs, excursions, and special events.

Hours and Services

The Digital Computer Museum is open to the public Sunday through Friday, 1:00 pm to 6:00 pm. There is no charge for admission. The Digital Computer Museum Lecture Series Lectures focus on benchmarks in computing history and are held six times a year. All lectures are videotaped and archived for scholarly use. Gallery talks by computer historians, staff members and docents are offered every Wednesday at 4:00 and Sunday at 3:00. Guided group tours are available by appointment only. Books, posters, postcards, and other items related to the history of computing are available for sale at the Museum Store. The Museum's lecture hall and reception facilities are available for rent on a prearranged basis. For information call 617-467-4443.

BOARD OF DIRECTORS

Staff

Gwen Bell
Director
Jamie Parker
Exhibit Coordinator
Christine Rudomin
Program Coordinator
Jay McLeman
Computer Technician
John McKenzie
TX-0 Technician
Beth Parkhurst
Research Assistant
Sue Hunt
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THE DIRECTOR'S LETTER

The museum's birth and parentage were responses to different needs that sprang from several sources. When Ken Olsen and Bob Everett saved Whirlwind from the scrap heap in 1973 and arranged to exhibit it at the Smithsonian, they also envisioned a place where all the treasures related to the evolution of computing could be preserved. Then Ken bought the TX-0, the first full-scale transistorized computer, when it came up for auction. Soon word went around that he was maintaining a warehouse for old computers and the industry responded with donations of a LILAC, a PDP-8, and other classic machines that otherwise would have been junked.

At the same time, Gordon Bell was also thinking about a computer museum, an idea which emerged while writing Computer Structures with Allen Newell between 1967 and 1970. They studied all the computers to that date and developed PMS, a notation capable of characterizing all information processing systems. While writing about the machines, Gordon started visiting them and bringing back artifacts. Soon his office and home were filled with modules of the Atlas, the IBM 650, the ILLIAC II, memory devices that predated the core, and calculators that preceded computers.

Still, Gordon was complacent with the thought of a potential museum until he travelled to Japan where Fujitsu proudly turned on its first relay computer for him to admire. He was convinced. If the Japanese could pull this off, then he, Ken Olsen, and Bob Everett should be able to display the TX-0 and other early machines. But there was no budget or space for the Museum.

This time, RCA saved the day. The Marlboro "tower building" constructed by RCA in 1970 and later purchased by Digital had a grand lobby and open balcony waiting to be used for exhibits. Gordon thought that it might somehow provide a setting for the TX-0, and he formed a volunteer committee to evaluate the space.

I was one of the volunteers. Having used the TX-0 in graduate school, I knew how the room felt at MIT, and the balcony area seemed reminiscent of that. The building's residents agreed to accommodate the museum collections. Two college students were hired for the summer to catalogue the artifacts in Gordon's office, photograph the computers that Ken had accumulated in the warehouse, and assemble exhibits with the aid of Digital's industrial designers. Gordon applied the PMS taxonomy from Computer Structures and wrote the text panels for the exhibits.

On September 23rd, 1979, the Digital Computer Museum opened with a lecture on the EDSAC by Maurice Wilkes. And while Ken and Gordon were very proud, that the collections had been assembled, no one was available to attend to the business of maintaining the collection, providing tours, or accepting new donations.

In November 1979, Jamie Parker, a recent Vassar College graduate, was hired as the first employee and the Museum became operable on a daily basis. A year later, the Operations Committee of Digital Equipment Corporation decided to develop a truly representative, industry- wide museum for the preservation of computing history and I was hired as the Director.

Digital Equipment Corporation not only provided start up funding, but encouraged employees in the legal, financial, marketing, public relations, administration, sales and service, and engineering departments to donate their time and talents to this cause. The birth of the Museum is coincident with the twenty-fifth anniversary of the founding of Digital Equipment Corporation; and the Museum is the corporation's twenty-fifth birthday present to the public as a way to insure the preservation of the history of computing for future generations.

Establishing the Full-Fledged Public Museum

My first task was to transform a private collection into a public foundation with full charitable status. A distinguished board of directors, representative of the diverse nature of the information processing industry, was assembled. The Members Association encourages participation by anyone interested in the Museum's focus and activities. These two groups provide the interface between the Museum's public and its staff, keeping the direction on course and responsive.

The staff has grown and taken on specialized roles. Jamie Parker, exhibit coordinator, planned the Pioneer Computer Timeline, and finds a place for each significant new acquisition. Chris Rudomin, program coordinator, organizes the lectures and seminars, the store, and educational programs. Sue Hunt is the Museum's coordinator of everything else and with a bank of word processors provides our day-to-day support. Jay McLeman, a full time staff member, cares for the operating machines. John McKenzie, who is TX-0's lifetime technician, is working on the long and arduous re-entry of the TX-0 into the world of operating computers.

A phalanx of students tackle special projects. Since the fall of 1980, Professor Mary Hardell of Worcester Polytechnic Institute has arranged that computer science students can complete their Interactive Qualifying Project at the Museum. These range from research papers on benchmark programs, such as Space War on the PDP-1, to preparing explanations of exhibits, such as the Atanasoff-Berry Computer breadboard. Beth Parkhurst has a part time position while she is a fulltime PhD candidate in the History of Technology at Brown University. She wrote the text for the Pioneer Computer Timeline and is editing a videotape of the ENIAC made from old newsreel films. Five additional college students will be hired for this summer.

As Director, I have focussed on acquiring artifacts, conceptualizing projects, and acting as the Museum's spokesperson. On a trip to England in February we acquired the micro-processor from the EDSAC 11 from the Science Museum, the console of the IBM 360/195 from Rutherford Labs, a full-scale Williams tube, and a logic door from the Ferranti Mark I' from the University of Manchester. Documentation services and a photo and film archive will be realized in the next year. In October I chaired a session on Computers in Museums at the Association of Science and Technology Centers meeting at the , Exploratorium in San Francisco and have consulted with other Museums including the Capitol Children's Museum, Washington; The Science Museum, London; the Ampex Museum, Redwood City; and The National Museum of Science and Technology, Ottawa.

Guidelines for the Future

Our main thrust is to develop the collection and continue the tradition of saving classic machines from the junk pile. We rescued the last operational STRETCH, saved the major components of the very first CDC 6600, and collected the Philco-Ford 212 before it was to be scrapped. The first priority is saving history, the second is to display it, and then the third is to interpret its historic role. The exhibits, therefore, are dynamic and evolutionary.

Five tested policies have crystallized.

1. The major purpose of the Museum is the historical preservation of the evolu- tion of computers. To that end, the PMS notation forms the basis of the taxonomy determining the extent of the kingdom of computing and providing guidelines for exhibits. Jan Adkins of the National Geographic Society captured the essense of the venture when he said to me, "You must feel like the Director of the Museum of Natural History when he started to collect bones."

2. The lecture series that started with talks on pioneer computers by people who had personally worked with them will be expanded to a series of seminars in a similar vein. Andy Knowles, a member of the Museum's Board, is fond of reminding me that, "There is no history, only biography." Thus, we are giving the podium to people who can give first-hand biographies of machines, programs, and languages they have known.

3. The focal point of the Museum is the machines themselves. Frank Oppen- heimer, the Director and Founder of San Francisco's

Exploratorium counsels, "Well-engineered machines speak eloquently of their own elegance. Museum designers can't equal them." Revealing the intrinsic beauty and functionality of the exhibited machines is our challenge and goal.

4. The main audience for the historic and archival collections are computer scientists, programmers, history buffs, and those with a curiosity about computer evolution. The Museum will provide a sense of the feel of machines and programs from various eras. Spacewar, the first computer game, feels totally different run- ning on the 1961 PDP-1 than it feels on a small arcade machine. This is hardly apparent to a youngster whose only Spacewar experience is in an arcade, but it is the feel of the PDP-1 that almost brings tears to the eyes of those who were computing during its era. As board member George Michael says, "Hey, this is a Museum for us big kids."

5. The Museum encourages broad-based involvement by maintaining a good working relationship between the enthusiastic volunteers, donors of artifacts, patrons, students, scholars and a staff that can keep stirring the soup. Harold Cohen, creator of our computer-designed murals, observed that the Museum doesn't. . . "have to convince the computer community to support the museum because its artists are worth supporting; they are the artists. It is completely different from any other museum that I know."

Because the Digital Computer Museum is unique, its rules need to be invented. This inaugural report provides a baseline from which the Museum can flourish in a multitude of directions. I hope that you will join me in this process.

Gwen Bell
Director

Unusual Photos

This 1953 transistor had its own serial number and was individually packaged. The tube was indented to hook the transistor over the side and keep its 'whiskers" from becoming bent.

The Pascaline (1645) is the first mechanical, single register calculator built that is still in existence. Roberto Guatelli reproduced this copy from an original in the collection of Thomas Watson stored by IBM. The calculator was designed by Blaise Pascal, the famous French scientist and philosopher, at the age of 19. Although a number were built during his lifetime, the tooling was such that they were unreliable, and became curiosities as much as calculators. The principles of Pascal machines were later applied to key punch calculators such as the Comptometer.

This drum is the only remaining portion of the Atanasoff-Berry Computer, the first electronic, digital calculator. Two drums were built, each with 32 50-bit tracks of small paper condensers, with the outer end connected to a contact stud and the inner ends connected together and brought out through the mounting plates. The space near the periphery, in which the condensers are mounted, contains a high grade of wax for moisture protection. A positive charge on the outer end of a condenser corresponds to zero, a negative charge to one. The drum rotates on an axis at a speed of one revolution per second. Brushes bear upon their contacts to read the charges and recharge them.

LECTURE SERIES

Maurice Wilkes spoke at the inauguration of the first exhibits, September 23rd, 1979. The eleven other lectures given to date include nine by people closely associated with the machines featured on the Pioneer Computer Timeline, one on the Computer Murals and one on the LINC. These lectures were recorded on video-tape for the Museum's archives. Six major lectures relating to the exhibitions at the Museum are planned each year.

Wesley Clark, November 18, 1981 The Design, Building, and Use of the First Laboratory Computer: LINC "The concept of putting this in one box that an experimenter could take away to his laboratory and work with in a personal way was the essence of it." "One fellow looked at the LINC inside and out, and at this wire going over and to the other side. Then said, 'This thing can't possibly work, there is no way to get the data in.' He couldn't find any punched cards. We went back to Lincoln Laboratory exhausted but triumphant, wanting to do more."

Maurice Wilkes, September 23, 1979 The Design and Use of the EDSAC
"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."

George Stibitz, May 8, 1980 The Development, Design and Use of the Bell Laboratories Relay Calculators
"In 1939, it was funny to think of a machine that calculated in the ancient binary notation. I wasn't sure whether the idea was funny or not, and for several weeks I thought it over, drawing circuits at home for a real calculator with desk-top capabilities."

Jay Forrester, June 2, 1980 The Design Environment and Innovations of Project Whirlwind '
"The Whirlwind experience was a very good beginning because we learned the problems of pioneering, we learned the need for courage to stand up for what you believe." "Magnetic core storage, marginal checking, high reliability, cathode-ray displays, light gun, and a kind of time-sharing were all part of Whirlwind."

John Vincent Atanasoff, November 11, 1980 The Forces that Led to the Design of the Atanasoff-Berry Electronic Calculator
"I soon found that no machine or system available could solve the growing lists of problems of theoretical physics, technologies, statistics, or business." "There I was in 1936, turning my mind to invent a digital machine, not knowing how it would be built or how it would work .... In a larger sense no man invents anything; he builds and extends a little with his friends and on the shoulders of others."

Konrad Zuse, March 4, 1981 Designing and Developing Zl - Z4
"At that time, nobody knew the difference between hardware and software. We concentrated ourselves on purely technological matters, both logical design and programming. "

James Wilkinson, April 14, 1981 he Design and Use of the Pilot ACE

Right from the very start, Turing was very obsessed with getting the maximum possible speed. That wasn't the popular view at the time."

John Brainerd, June 25, 1981 Development of the ENIAC Project
"It was the world's first large-scale digital electronic general purpose computer. You have to put all those words in to tell some thing about it."

David Edwards, September 9, 1981 The Evolution of the Early Manchester Machines
"F C. Williams's contribution was that he recognized that if you looked at the patterns on the face of a tube after a millisecond, you could recognize what they were, and in looking at them you wrote them back again." "In June 1948, when the baby machine ran, our confidence started to develop."

T H. Flowers, October 15, 1981 Design and Use of Colossus
"During World War II, I became involved in code- breaking activities for which I conceived and built machines which became own as Colossus. Colossus had features w associated with digital computers - semi-permanent and temporary data storage, arithmetic and logic units including branching logic and variable programming. "

Arthur Burks, February 18, 1982 The Origin of the Stored Program
"This most important historical achievement [the stored program] did not come about in a straightforward way, but in a convoluted, indirect manner."

October 7 at 5 PM LECTURE: HISTORY OF THE SIEVE MACHINES D. H. Lehmer Professor Emeritus University of California j at Berkeley.
With an exhibition of the electro-mechanical machine used for finding prime numbers exhibited at the Chicago World's Fair of 1932 and the 1950 electronic prime number sieve.

October 8-9 **EXCURSION: ANFSQ7 and NATIONAL MUSEUM OF SCIENCE AND TECHNOLOGY**
Friday noon leave Hanscom Field for North Bay, Canada. Visit and tour the ANFSQ-7, vacuum tube computer in operation on the SAGE early warning system. Hotel accommodations in Ottawa. Saturday morning tour of the Computing Exhibition, National Museum of Science and Technology. Saturday noon leave Ottawa for Hanscom Field, Bedford. Contact Chris Rudomin for more information.

October 22 at 5 PM **LECTURE: THE WATSON SCIENTIFIC LABORATORY, 1945-50**
Herbert J. Grosch As the first assistant to Wallace Eckert and director of the computing program, Herbert Grosch will provide a narrative of the development of the Columbia Laboratories up to the time of NORC.

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The Computer Museum Report

Volume 2 ---- Fall 1982

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The Apollo Guidance Computer

A Designer's View

Eldon Hall ***Designer, Apollo Guidance Computer***

In the early sixties the so called mini-computer had not emerged and there was no commercial computer suitable for use in the Apollo mission. Most of the technologies that were eventually used in the Apollo computer were just emerging from research and development efforts. The design was mainly a task of fitting the components together in order to meet the mission requirements for computational capacity and miniaturization.

From Polaris to Apollo

Previous aerospace computers greatly influenced the development of the Apollo Guidance Computer. The demands that were placed on these computers provided the motivation to miniaturize and develop semiconductors. The MIT Instrumentation Lab, now called Charles Stark Draper Laboratory, had the responsibility for the design of the computers used in the Polaris, Poseidon, and Apollo programs.

The lab's first significant venture into the field of digital computing was for Polaris, a very small ballistic missile launched from a submarine. A special purpose digital computer was designed to solve the specific equations required for the guidance and control system based on analog techniques originally developed by the Navy. With the need for increased accuracy the Navy decided to use digital techniques for the Polaris program, resulting in the construction of a wired-program special purpose computer to solve the guidance and control equations. In 1959 the first version of this system, called the Mark 1, flew in a Polaris missile. It was the first guided flight of a ballistic missile flown with an on board digital computer providing the guidance and control computations. The computer occupied about four-tenths of a cubic foot, weighed 26 pounds, and consumed 80 watts. Even before this first guided flight designs were being explored which would reduce the size and improve the maintainability of the system. The new design, eventually designated Mark 2, repeated the architecture and logic design with improvements in circuits and packaging.

In August 1961, when NASA contracted the laboratory to develop the Apollo guidance, navigation, and control system, the mission and its hardware was defined in only very broad terms. A general purpose digital computer would be required to handle the data and computational needs of the spacecraft. Therefore a special arrangement of display and controls would be necessary for in-flight operations.

The boost phase of the mission, which was the Saturn system, had its own internal guidance system to put the command and service module in translunar trajectory Then the Apollo system took over to guide the mission to the moon.

In effect, navigating in space is the same as navigating on Earth. One might take a star sighting with a sextant. That information is put into the computer and from it the state vector, i.e. the position and velocity of the missile at any point of time, is computed. The computer orients the missile such that the change in velocity will cause the state vector to be updated so the missile will free-fall into the targeted point. While it is thrusting, the guidance system must control the attitude of the vehicle, the magnitude of the thrust in the case of the Lunar Excursion Module (LEM), and the direction of the thrust in the case of the Command and Service module.

Design Constraints

Initially the need for a very reliable computer with significant computational capacity and speed was clear. The design constraints included very limited size, weight, and power consumption. If the designers had known then what they learned later, or had a complete set of specifications been available as might be expected in today's environment, they would probably have concluded that there was no solution with the technology of the early sixties.

Establishing interface requirements was a monumental task. The astronaut interface was one of these. In 1962, computers were not considered user friendly. Heated debates arose over the nature of the computer displays. One faction, which usually included the astronauts, argued that meters and dials were necessary. Logically, the pressure for digital displays won most of the arguments because of their greater flexibility in the limited area allowed for a control panel. In late 1963, as the requirements for the LEM were being firmed up, NASA decided to use identical guidance computers in both the command module and the LEM.

Major units of the CM Guidance. Navigation and Control System.

In the early manned orbital missions before Apollo, NASA learned that the human animal, confined in a spacecraft for a week or so, was not as clean as might be expected from observations on Earth. This additional constraint had a rather interesting and farreaching impact on the mechanical design of the computers and other hardware. All electrical connections and metallic surfaces had to be corrosive resistant and even though the computer was designed to have pluggable modules, everything had to be hermetically sealed.

The Suppliers

By the end of 1962, NASA selected three contractors: General Motors' AC Sparkplug Division for the inertial systems and system integration; Raytheon, Sudbury Division, for the computer and computer testing equipment; Kollsman Instrument for the optical systems; North American Aviation for the command and service module; and Grumman Aircraft for the Lunar Excursion Module.

In late 1959 and 1960 the lab began evaluating semiconductors, purchased at $1,000 each from Texas Instruments. Reliability, power consumption, noise generation, and noise susceptibility were the prime subjects of concern in the use of integrated circuits in the AGC. The performance of these units under evaluation was sufficient to justify their exclusive use in place of the core transistor logic proposed initially for the Apollo project design. The micrologic version of the Apollo computer was constructed and tested in mid 1962 to discover the problems that the circuits might exhibit when used in large numbers. Finally in 1964 Philco-Ford was chosen to supply the integrated circuits used in the proto type computer that operated in February 1965. These cost approximately $25 each.

Specifications

Approximately one cubic foot had been allocated in the command module for the computer. The first prototype was operating in the spring of 1964 and utilized the wire wrap and modular welded cordwood construction which had been produced for the Polaris program. It was designed to have pluggable trays with room for spare trays.

Since the clock in the computer was the prime source of time, it had to be accurate to within a few parts per million. The data and instruction words in the memory were 15 bits plus parity. Data was represented as 14-bit binary words plus the sign bit. Double precision operations were provided to supply 28-bit computations. The instruction word contained the address and operation codes for the computer operation. The memory address field was extended by organizing the memory in banks.

The AGC had 2,00015-bit words of erasable core memory and started with 12,000 words of readonly memory, called rope memory. It was quickly upgraded to 24,000 words. Then by mid-1964, when the first mission program requirements had been conceived and documented, there was increasing concern about the possible insufficiency of the memory. This prompted a further expansion to 36,000 words.

Design and Use of the Console

A display and keyboard was developed for the astronauts and had the designation DSKY (pronounced "Diskey'). Functionally the DSKY was an integral part of the computer, and two were mounted remotely and operated through the discrete interface circuits. One was for a sitting position and another one near the entry to the LEM, convenient for a reclining position.

The principle part of the DSKY display was a set of three numeric light registers. Each register contained 5 decimal digits consisting of segmented electroluminescent lights. Five decimal digits were used so that a computer word of 15 bits could be displayed in either decimal or octal. In addition, three two-digit numeric displays indicated the major program in progress, the verb code and the noun code. The verb/noun format permitted communication in a language whose syntax was similar to that of spoken language. Examples of verbs were display, monitor, load, and proceed. Examples of nouns were time, gimbal angles, error indications, and star identifications. Commands and requests were made in a form of sentences, each with a noun and a verb, such as display velocity or load desired angle. To command the computer the operator pressed the Verb key followed by a two digit code. This entered the desired verb into the computer. The operator then pressed the Noun key and a corresponding code. When the enter key was pressed, the computer carried out the operation that had been commanded. The computer requested action from the operator by displaying a verb and noun in flashing lights so as to attract the astronauts' attention.

The read-only memory of the computer consisted of six rope memory modules, each containing 6,000 words of memory. This special type of core memory depended on the patterns set at the time of manufacture. Its sensing wires were woven into a set pattern information. It had five times the density and was far more reliable than the coincident current core memory used for erasable storage in the computer. Being unalterable, it also provided a greater incentive for error-free software development. The AGC rope memory is on display in the primary memory case.

In-flight Use

Shortly after liftoff of Apollo 12, two lightning bolts struck the spacecraft. The current passed through the command module and induced temporary power failure in the fuel cells supplying power to the AGC. During the incident the voltage fail circuits in the computer detected a series of power trenches and triggered several restarts. The computer withstood these without interruption of the mission programs or loss of data.

The module in the background is exactly the same as one in the foreground, but it has only been used on Earth. The Museum's prototype computer ran at Draper Labs and was used to test the routines for the in-flight machines. In space all of the components had to be totally "potted" to insure that all the parts would stay firmly in place and remain uncontaminated during space flight.

The Apollo 11 lunar landing had an anomaly which attracted public attention. The computer in the LEM signalled a restart alarm condition several times during a very critical period prior to touchdown. This fact was broadcast to the public and those who knew its significance were close to a state of panic. After analysis, it was determined that the alarms were an indication to the astronauts that the computer was overloaded and was eliminating low priority tasks from the waitlist.

The overload resulted from the rendezvous radar being set in the wrong mode during the lunar landing phase, wasting computer memory cycles. The computer software was responding to overloads as designed.

This incident triggered a news brief in Datamation in October, 1969, faulting the computer design for being too slow. It rightfully claimed that there were a number of minicomputers, including the PDP-11, that were at least an order of magnitude faster. In the eight years since the initiation of the Apollo program commercial technology had far surpassed that of the Apollo design and capacity. However, no commercial computer could claim to match the power consumption and space characteristics of the AGC.

The Apollo Guidance Computer, shown on the left, was responsible for the guidance, navigation, and control computations in the Apollo space program. The AGC was the first computer to use an integrated circuit logic and occupied less than 1 cubic foot of the spacecraft. It stored data in 15 bit words plus a parity bit and had a memory cycle time of 11.7 microseconds, utilizing 2,000 words of erasable core memory and 36,000 words of read-only memory. The frame is made of magnesium for lightness and designed to hermetically seal the components.

The interface with the astronauts was the DSKY shown on the right. It used digital displays and communicated with the astronauts using the verb and noun buttons visible in the photograph and two digit operation and operand codes. A set of status and caution lights is shown in the top left corner of the DSKY

The AGC and DSKYare on display in the Four Generation

Gallery.

Excerpted from an Illustrated Lecture, June 10, 1982, by Ben Goldberg. The video- tape is archived by The Computer Museum.

The Apollo Guidance Computer

A Users View

David Scott ***Astronaut for the Gemini 8, Apollo 9, and Apollo 15 missions.***

In 1963 when NASA was conducting the selection of the third group of astronauts for the U.S. space program, I had just received a graduate degree at MIT and finished test pilots school. My interests and the program's need for a user to interact with the design of the guidance computer at the MIT Instrumentation Lab was a good fit. I was part of those discussions whether to use analog or digital controls that Eldon described.

The MIT Interface

When I was studying at MIT, the ability to rendezvous in space was an issue for debate. It wasn't clear whether it was possible to develop the mathematics and speed of computation necessary to bring two vehicles together at a precise point in space and time-a critical issue for the Apollo missions successful landing on the moon and return to Earth. Between 1963 and 1969, with the flight of Apollo 9 this was accomplished. I stayed in the spacecraft while Rusty Schweickart and Jim McDivitt got in the lunar module and went out about 60 miles away. The computer behaved flawlessly during our first successful rendezvous in space.

Another assignment for Apollo 9 was to take the first infra-red photographs of the Earth from space. To do this, a large rack of four cameras was mounted on the spacecraft. Since they were fixed to the spacecraft, the vehicle itself had to track a perfect orbit such that the cameras were precisely vertical with respect to the surface that they were photographing. During simulations it was determined that manual orbit procedures would be inaccurate. We were at a loss. About two weeks before the flight I called up MIT and asked if they could program the computer to give the vehicle a satisfactory orbit rate. They answered, "Of course, which way do you want to go and how fast?". In a matter of a couple of days we had a program and a simulator that automatically drove a spacecraft at perfect orbit rate. We got into flight with very little chance to practice or verify, but we put on the cameras and the results were perfect.

Potential Computer Failure

During the development process we ran many simulations of in-flight computer operations with particular concern for in-flight failure. But in the 10 years that I spent in the program there was never a real computer failure. Yet, people often wonder what a computer failure would have meant on a mission. It would have depended on the situation and the manner in which the computer failed. We probably would not have expired, but there were some parts of the mission in which a computer fail- ure would have been especially compromising. Navigation was not necessarily time critical but the lu- nar landing was very time critical. You could have a situation during a lunar landing in which, if the computer failed, the engine would be driven into the ground. Unless the astronaut could react quickly enough to stop it, the Lunar Module could have been flung on its side. Chances are that the astronaut could prevent such an event by switching to manual control of the vehicle. It must be remembered that the computer had been de- signed to be as reliable as pos- sible and the astronauts had a great amount of confidence in the machine.

And Problems of Success

We had a backup called the entry monitor system, which had a graphic display based on the accelerometers in the spacecraft. With this display the vehicle could be flown manually using pre-drawn curves to be followed for attitude, g-loading, and velocity. It was reas- suring to know that we were still able to return to Earth even if the Apollo Guidance Computer failed. During reentry there was a scroll in the entry monitor system and we could see the computer tracking the predetermined curves all the way to the landing site. As our skills and the computer programs improved over the years of the Apollo program, we came down closer and closer to the carrier. Finally, by the last Apollo mission they didn't park the carrier on the landing point.

Excerpted by Ben Goldberg from remarks after Eldon Hall's Lecture, June 10, 1982.

Whirlwind Before Core

Reminiscences of Jack Gilmore

In October, 1950, I joined the Whirlwind team. At that time the first thirty-two registers of toggle switch memory were working. The four variable flip-flop registers could be assigned to any one of the thirty-two addresses. They were able to demonstrate small mathematical programs such as the bouncing ball problem or solve simple differential equations. The first memory consisted of electrostatic storage tubes totaling 256 locations. We felt really rich with a full 256 variable registers to write our programs. We calculated the operation in the octal address and then looked up what was then called the sexidecimal conversion number (later the term hexadecimal was used). We had a little load program in the 32 registers and that bootstrapped the programs up into the memory in order to run them.

This 1951 photograph of Whirlwind shows Joe Thompson seated at the Flexowriter typewriting unit. Jack Gilmore is standing in front of the 256 x 256 point display used for alphanumeric and graphic representations of various computations. The display was utilized to plot solutions of partial differential equations for determining the optimal rate of pumping oil from underground caverns and also for displaying the optimal placement of television antennas for compliance with F.C.C. regulations.

The first thing that we were very anxious to do was to get an assembly program that would allow us to be able to write our programs using mnemonic symbols and expressing the numbers in decimal and octal. My boss, Charlie Adams, was concerning himself with that and so it became my job to write the assembly program. I'm fairly certain that if it is not the first, it is one of the very first assembly programs ever written. The only one that I know of that predates it was Wilkes' 'Load and Go' on the EDSAC.

In September, 1951, John Carr, later Chairman of Duke's Computer Science Department, and I wrote a document that explained how people could actually use subroutines in conjunction with assembly programs, so that they didn't have to write all the various utilities. People could write their programs in a relative fashion and then we would give them the library of subroutines and they'd actually pick out the tapes that they needed. We'd then string the tapes together and literally make a copy not only of their program but also of the subroutines. All of those would be pulled in through the bootstrap program and it would run. This was the indirect birth of the symbolic address. The thing that we discovered, I think I actually discovered it, was that when we ran the tape through twice, you could refer to an address above where you were, as opposed to everything going below. The two pass assembler came out of all that. I have a recollection of Charlie Adams and I briefing IBM's Nat Rochester on how to produce symbolic addresses.

The Ph.D. candidates who needed to use the Whirlwind really didn't know how to run the machine. There were full scale electronic technicians who knew how to bring it up, and most of the systems programmers like myself knew how to do it, as well as some of the engineers. It was a fairly routine procedure so I went to Charlie Adams and suggested that I could train two people right out of high school to be computer operators if I had enough funds to hire them for one year. Jay Forrester provided the funds and I went out to two local high schools and asked for students that were college material but didn't have the money for college. I hired Joe Thompson from Boston Technical High School (shown sitting down in the photograph) and Bill Kyle from Boston English. Within four or five months they were competent operators, and Joe stayed on to complete his degree at Lowell Tech in the eve- nings. One day Forrester came in and sat at the back of the room. He watched for about an hour while Bill and Joe completed eight or nine different jobs. Finally Jay said, "We've just created a new voca- tion." He also recognized this as the solution to the problem of computer operators for the SAGE project.

The flexowriter typewriting unit we used was a word process- ing system, originally designed for list processing and promotional mailings. It had a mechanical reader and would create a form letter in a loop with stop codes to key in the personal information. We used it as an integrated word processing system, circa 1951.

One Sunday afternoon in December 1951 the Whirlwind was featured on 'See It Now', Edward R. Murrow's program. Ron Meyer and I stayed up all weekend writing a program to display the trajectory of a Viking rocket on the display and another program that played Jingle Bells. They wired Jay Forrester with a mike and had the wire coming up his back with cables on the floor so he could walk from one part of the console to another. As he started to walk the wire snagged and the back of his coat started to come up. One of the CBS technicians decided that he was going to undo the snag and started to crawl across the floor like a commando. Forrester, not realizing that his coattails were at 90 degrees, couldn't understand why the technician was crawling towards him. We decided that Forrester was getting too distracted and so the technician was pulled back across the floor by his ankles. Meanwhile, Edward R. Murrow and Jay Forrester completed the interview which ended with Jingle Bells being played for the pre- Christmas viewers.

[The museum has archived a copy of the video tape of the Murrow in- terview in which Jack Gilmore may be seen loading the tape reader]

Extracted by Ben Goldberg from a Gallery Talk by Jack Gilmore, June 16, 1982.

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Highlights from
The Computer Museum Report Winter/1983

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Bell Telephone Laboratories Model 1 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, DI27.80.)

Zuse Zl, 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 GianCarlo 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 postwar 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 Zl, in the family living room. The Zl, completed in 1938, was followed in 1940 by the Z2, a prototype electromechanical 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 Sl 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 Englishlanguage 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 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."

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.)

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 1, 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

Colossus

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.

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.

"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."

1. 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 Col 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 x 102ø 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.

ENIAC

Each of these earlier machines had some of the features of the electronic computer. In the ENIAC, these features-electronic, highspeed operation, general-purpose capability, and program controlwere 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 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 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.

EDVAC

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.

IAS Computer

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, especially 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 piecewise 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.

EDSAC

"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

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

"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 Wlkes is on the back cover holding the memory driver's wiring. (On loan from the Science Museum, London.)

Manchester University Mark I

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

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

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; E 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 inspirationin the middle of which were two cathode-ray tubes storing digits in serial access mode-the 'Williams memory.' l 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

Pilot ACE

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 cryptoanalytic 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 Turings 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 alreadydeveloped 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 stmt 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. 1. T Servomechanisms Lab became director of the project. By 1945, the original conception of an analog machine was dropped, and the Navy approved 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.LT Libraries, Cambridge, MA.

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 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 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.LT Libraries, Cambridge, MA.

Whirlwind was thus the first 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	Memory size (words)	Add time	Memory type [secondary]	I/O	Technology	Floor space est. sq. ft.

Bell Labs Model I George Stibitz at Bell Telephone Laboratories	1939	10/39	4 function, complex arithmetic calculator	8 digits	4 working registers	6s for complex x (4 products)	none	Teletype or paper tape	450 relays	50
Zuse Z3 Konrad Zuse	1939	1941	punched film	22 bits, flt. Pt.	64	2s	relays	punched film, keyboard, lights	2600 relays	100
ABC John Vincent Atanasoff and Clifford Berry at Iowa State University	12/37	12/39 prototype 1942	fixed, equation solver	50 bits	2 x (30 + 2 spare)	32 in 1s	drum of capacitors	cards	vacuum tubes	12.5
IBM ASCC Harvard Mark I	1937	8/44	punched tape, function table, plugboard	23 digits also double precision	72 counters 60 switches	.3s	relays, switches	paper tape, cards, typewriters	relays, motor-driven cam, clock	51 ft long, lg. room
Colossus (Mark I & II) Bletchley Park	1943	12/43 (I) 5/44 (II)	telephone plugboard (I), switches (II)	5 bit characters	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)
ENIAC Moore School, University of Pennsylvania	1943	2/46	plugboard, switches	10 digits	20 accumulators, 312 function table	.2ms	counter tubes, relays, switches	cards, lights, switches, plugs	18,000 vacuum tubes, 1500 relays	1,000
EDVAC Moore School, University of Pennsylvania	1/44	1951	stored program computer	44	1024 (8 x 128)	.85ms	delay lines, [magnetic drum (1953)]	paper tape	3,500 vacuum tubes, 7,000 diodes	400
IAS Computer Institute for Advanced Study, Princeton University	6/46	7/51	"	40	1024	.09ms	crt	Teletype	2,600 vacuum tubes	100
EDSAC Maurice Wilkes at Cambridge University	10/46	5/49	"	36	512	1.4ms	delay lines	paper tape, teleprinter	3,000 vacuum tubes	med. room
MANCHESTER U. MARK I Manchester University	1947	6/48 prototype 7/49	"	40	128 + 1024	1.8ms	crt, [magnetic drum]	paper tape, teleprinter, switches	1,300 vacuum tubes	med. room

PILOT ACE National Physical Laboratory Teddington, England	10/48	5/50	"	32	352	.54ms	delay lines	cards	800 vacuum tubes	12
SEAC National Bureau of Standards	6/48	5/50	"	45	512 + 512	.86ms	crt, delay lines, [magnetic tape & wire]	paper tape, Teletype	1,290 vacuum tubes, 15,800 diodes	150
SWAC National Bureau of Standards Institute for Numerical Analysis	1/49	7/50	"	41	256	.064ms	crt, magnetic drum	cards, paper tape	2,000 vacuum tubes 2, 500 diodes	60
Whirlwind Servomechanisms Laboratory MIT	1945	1951	"	16	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.

Additional Source Material

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

C. Cordon 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 1. 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. Cluck, "The Electronic Discrete Variable Computer." Electrical Engineering 72, 1953.

IAS Computer

The LAS 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 70-12, 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 A(EE-IRE-ACM Computer Conference, New York, December 10-12, 1952.

Sidney Greenwald, R. C. Haueter, and S.N. Alexander, "SEAL." 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 Consultation 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.LT 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 CoincidentCurrent Magnetic Memory Cell for the Storage of Digital Information. Proceedings of the IRE 40, 1952.

William N. Papian, "The MIT MagneticCore 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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Highlights from

The Computer Museum Report

Volume 4 ---- Spring 1983

Contents of Highlights

D.H. Lehmer's Number Sieves

Richard Rubinstein

Richard Rubinstein, a human factors engineer at Digital Equipment Corporation and an active volunteer at The Computer Museum, compiled this article, based on his experience planning and supervising the Lehmer Number Sieves exhibit.

Dick Rubinstein (left) and Derrick Henry Lehmer (right) pause in front of Lehmer's Photoelectric Number Sieve after Lehmer's dedication of the exhibit, October 7, 1982.

This Photoelectric Number Sieve, built by Dr. Lehmer in 1932, performs 300,000 tests per minute using 30 gears arranged tangentially. Each gear has a number of holes equal to a multiple of a prime. For any problem, all holes that do not represent solutions are plugged with toothpicks. A solution is found when light, originally supplied by an automobile headlight lamp, passes through all 30 wheels. A Photoelectric cell detects this brief flash of light, and a vacuum-tube amplifier multiplies the resulting signal 700,000,000 times to stop the motor.

Number sieves perform. tests an numbers to eliminate those numbers that cannot be solutions to a problem, and thus find those that are solutions. Dr. Lehmer's machines search numbers sequentially, from any starting point that may be chosen, looking for a number that has an acceptable remainder modulo, each of a number of primes.

Consider the following problem:

> Find a value of x for which
> $91894770302976x^2 + 287722528867021824x + 256527596541064768$
> is a perfect square.

These large coefficients are not arbitrary numbers. In fact they arise quite naturally in an investigation into the possible factors of the Mersenne number $2^{79} - 1$. The numbers $2^n - 1$ where n is a prime have been the subject of investigation since time time of Euclid. Twelve of these numbers have been praved prime and twelve composite ones have been completely factored. Since 1924 it has been known that if a value of x exists for which the formula above is a square then

> $0 < x < 39110012.$

D.H. Lehmer explored the problem with his photoelectric number sieve. The problem was considered in each of the finite arithmetics corresponding to a prime or a power of a prime where $p < 127$, and the appropriate holes in the corresponding gears were stopped up. This presents the problem to the machine, which, canvassing numbers at the of 300,000 a minute, can cover the above range far x in about two hours without attention. As a matter of fact, during the first test the power was automatically shut off in 12 seconds and the machine coasted to a stop.

Reversing the machine slowly and substituting the human eye for the photo-electric cell, the light was seen to shine through at

> $x = 56523$

according to the reading on the revolution counter. Substituting this value of x in the formula we obtain at once the number

> 309853160646773276521024,

which is the square of 556644555032. Hence our problem is solved. Incidentally this leads to the factorization:

> $2^{79} - 1 = 2687 \cdot 20202978 \cdot 1113491139767.$

Derrick Henry Lehmer is the son of a leading American number theorist, Derrick Norman Lehmer (1867-1938). D.H. Lehmer designed and built the number sieves shown in the accompanying photographs of the Museum's Number Sieve exhibit to further his own research in number theory. He presented the number sieves to the Computer Museum, and on October 7, 1982, he dedicated the exhibit with a lecture on the sieves. Videotapes of his lecture are in the Museum archives.

As a user of ENIAC, Dr. Lehmer was in charge of operations, maintenance, and much of the trouble shooting. Dr. Lehmer continues to use computers, such as the Cray 1 and ILLIAC IV, to support his work with number theory. He is professor of mathematics Emeritus at the University of California, Berkeley

The number sieve idea dates back to the Greek Eratosthenes who lived in Alexandria about 230 B.C. His sieve provided a way to find prime numbers by removing composite numbers from a list of the positive integers.

The first mechanical realization of a sieve process was over 200 years ago, by Karl Hindenberg, a German, and Anton Felkel, an Austrian. They invented what is now called the stencil method. Using this technique, Felkel produced a compilation of the factors of the integers up to 408,000, published by the Austrian government in 1776. Few copies were sold, and those remaining were scrapped and used for making cartridges for the war against Turkey.

These sieves were specialized, useful only for finding primes and for finding the factors of composite integers. A more general approach, the strip method, used by A.M. Legendre in 1794, allowed searching for numbers with far broader properties, but was still a slow and error-prone manual technique. The strip method was the best available technique when D.H. Lehmer developed his first machine.

Dr. Lehmer built the first electromechanical number sieve in 1926. It used 19 bicycle chains, and performed a process similar to the strip method. The rotating chains simulate the effect of the shifting strips of paper, and have the major advantage that no upper limit of the search need be established at the outset. The machine can be left running indefinitely in search of numbers with the desired properties. In 1932, Lehmer built a far faster machine using 30 tangential gears, capable of performing 300,000 tests per minute. Later, he also built a sieve that used 16mm film, and another with vacuum tubes and delay lines. These machines did efficiently and inexpensively what no commercial calculating equipment then available could do at all.

This small sieve, employing 16mm film as the computing elements, was built as a complement to the large photo-electric machine. It was used for relatively short problems, and performed about 3000 tests per minute. Easier to set up than the photoelectric model, it could be supplied with as many as 18 film loops.

The Bicycle Chain Sieve, built in 1926 but later destroyed, is being replicated at the Computer Museum by Roberto Canepa, Andrew Kristoffy and Richard Rubinstein. This photograph shows the Museum's working model before the installation of micro-switches and a counter. The original 19-chain machine could perform 3000 tests per minute. It was used to factor the number:

9999000099990001

which is a factor of $10^{20} + 1$. The machine ran for about two hours, finding the solution:

1676321 • 5964848081

Constructed in 1966 as an unsponsored educational project of the Departments of Mathematics and Electrical Engineering at the University of California, Berkeley, the Delay Line Number Sieve performed 1 million tests per second. Navy surplus delay lines store the acceptable remainders for each modulus and circulate them synchronously. The machine has an idle mode in which all of the delay lines are connected in series and the data recirculated, so that the machine may be "stopped" and loaded.

"In competition with the IBM 7094 [it] makes a good showing, especially on economic grounds. It is roughly 10 times faster than the 7094, and costs about 2 cents an hour to operate."
D.H. Lehmer

Inside "The Soul of a New Machine"

Tracy Kidder and Tom West

Tracy Kidder (left) and Tom West (right) discuss The Soul of the New Machine during the Museum's Bits and Bites series.

Tom West: I think it's probably important to point out that Tracy and I have never done this before . . . and will probably never do it again! I am still doing com- puters and Tracy is still writing books. Neither of us has yet become PR. junk- ies, but that may change after looking at such a large group of people who seem to think we have something to say.

Tracy Kidder: We would like to find out what you are interested in and try to answer your questions.

Q: How did you two first get together? Did you start writing at the time the project was started? **Kidder:** About six years before I started, I had been a journalist writing for the Atlantic Monthly. I went in to my editor one day because I had nothing to do and asked him what I should do next. He said "Look into computers." I asked where I should start and he told me to go see West, whom he knew. So I did and then one thing led to another.

West: It was a little more complex than that. Tracy decided that he was going to write "The Book" about all computers. He went to the library and found that there had already been many stories written about the whole world of com- puters. Then it was going to be the whole world of mini-computers, which I suspect even today is too big a story to tell. It kept narrowing and narrowing, until, rather accidentally it became focused on a single machine.

Q: What was it like for you, as someone who is used to working with machines in a crisis situation, to be shadowed by a person with a notebook?

West: There are some real advantages to having a writer on a project. Tracy was about the best early warning sys- tem you could imagine. I would suggest that every program manager hire some guy from the street, teach him how to write on steno pads and have him walk around listening to people. The young engineers walk around thinking that this must be an incredibly important program because somebody is writing about it. One disadvantage is that you could wind up with the most well- recorded failure in history.

Just Tracy looking at the thing actu- ally changes the way it works. There is all this uncertainty involved. It's not the way it would work under normal circum- stances, it has been perturbed. It is a little disarming to wake up in the morn- ing, go down to breakfast and find Tracy Kidder interviewing your wife and two daughters with a steno pad.

Kidder: Most good journalists, and I certainly aspire to be one, think of them- selves as good anthropologists who come in to observe the customs of the natives and don't want to change those customs in the process. Just the fact that you are there changes things. But, if you are never there at breakfast then you would never know what happens at breakfast.

Q: What sort of reaction did you get from Data General and from people in the book, after the book came out?

West: For me, it was like three years of psychoanalysis embedded in about twenty-four hours. I hadn't read the book before Tracy went to the printers with it and I don't think many of the other people had either. It was a shock then, to all of a sudden see a whole piece of your life in print, a piece that maybe you would have chosen to rewrite very care- fully.

I don't think Data General was cer- tain, even after reading the book, what the public reaction was going to be. It was a fairly accurate representation of what they do every day for a living. And I don't think that the story is unique. Otherwise, why do so many people read the book? Why do so many people buy the book and send it home to Mom to explain what they do? And why do they give it to their girl friends to explain that this is the reason they are not home until eleven o'clock at night? The general answer is that the everyday life of designing computers had been pretty opaque.

But from my point of view the re- viewers tell you what you are supposed to think about the character.

Kidder: That's right, you have been called Captain Ahab, The Prince of Darkness, Machiavelli, Tom Swift . . .

West: Gatsby and Horatio Alger. It's been kind of eerie.

Q: The paperback book says it is soon to be made into a major motion picture. What is exciting to the lay person about high technology?

Kidder: I think this is kind of fun, frankly Columbia wanted to turn this into a movie, one way or another. As to why they find it interesting, I don't know. I found the story interesting and I rate as a lay person. At one time during my research, Data General had some understandable fears about trade secrets. West pointed out in a rather sardonic way that I would never learn enough to be able to convey a trade secret.

West: When people ask why D.G. allowed a Pulitzer Prize winning book to be written about their machine, that is not what they agreed to. A guy was going to write a little piece about a couple of guys sitting down in a lab sort of dreaming up their own thing. Even at printing time there was really no way of knowing that there was quite so much interest in Tracy's book.

Q: What are some of the advantages of a closed management style versus a more open one?

West: In support of this sort of closed management style, I knew more about what was going on in every single one of those organizations than any manager at that level in most companies does. It's not a question of not having the information, it's a question of not having the style.

If somebody walks into your office after five minutes of staring at a sheet of paper and asks: "Should we make this register sixteen bits wide or thirty-two bits wide?" you know the answer to this question if you have been through it over and over and over again. So you can tell him the answer, and he goes back and puts it in. Then he sits around for another five minutes before coming back with the next question. In some sense that is sort of what happens.

If you can send him back to his office and he thinks a little while longer, ten minutes, fifteen minutes, or a half an hour, and then he gets a little scared because he's got to have the right answer by the time he goes back in again, you extend his span of attention before he is finally ready to go and scream for help.

It seems to me that that is one of the most valuable lessons that you can teach a kid who is coming into this business right out of school. A span of attention of five minutes or even a half an hour is not really going to do it. There are some problems that only yield after three hours of just staring at them. I'm sure all of those who have been doing design work have seen exactly that same thing happen. It is the ability not to give up even after two hours of trying to stare something down. Part of that is what is embedded in that whole style of trying to make the easy answers difficult to get.

Q: It is very clear at the end of the book that you couldn't keep a good team together, but it is also sort of sad that so many of them end up leaving Data General.

West: At the end of this program, an awful lot of people, not only left the program, but also left Data General. This is not a totally anomalous phenomenon to D.G. People don't leave projects in the middle, they leave them at the end, with an incredible postpartum depression at the end of something that they poured so much adrenalin into. They go home and with more time on their hands. They begin to ask themselves why the heck they ever did it in the first place and would they ever be willing to do it again. If the answer is yes, then what are the odds of their doing it successfully again? Is it a coin toss, fifty-fifty each time, or do the odds keep piling up against you?

I read in Time Magazine that statistically I'm burned out and washed up at forty-three. I think there is going to be not only a shortage of engineers in the next ten years but a shortage of engineering managers with enough street sense to be able to manage all the college graduates who are graduating with all kinds of notions about things that can be done but quite possibly shouldn't be done. Just like all these people who are putting 68000s on a board and calling it a computer. There is going to be a great need for people to be able to see the way technology is going and be able to manage these people coming out of school.

In this machine we had a straightforward design. We were highly leveraged on PALS because it provided quite a bit of logic compression. Almost everyone drew out these PALS, except the guy who was designing the system cache. He was doing it all on four by five file cards. Every week or so I'd ask him how he was coming on his design. He'd show me this big deck of file cards with Boolean equations written on them and a whole room full of Karnaugh maps and things to try to reduce these down to something that made sense. There was no way of telling where the guy was. Design review time was coming and all the managers were getting anxious. The big deck of cards was still there, and he was still worrying about the various mapping things that he'd learned in college. We really came perilously close to firing that guy But finally when the design review day came, it was a deck of cards with a well-defined set of Boolean expressions for each one of those PALS. We used one hundred and sixty of them in the machine and about forty of them on the system cache. He built the thing, and it worked the first time. At that stage of the game I said to myself; thank God I didn't fire him.

Q: Would you attribute the intimidation some of your subordinates felt toward you to their inexperience?

West: In the first place, I would sure hate to defend what I did four years ago. At some level in the organization you expect to have people who are going to fight back, regardless of what the issue is, if they feel strongly about it. If they don't feel strongly about it, then they had better go away and do it your way

Q: The book mentions the fun part, the engineers doing the design, but I don't remember hearing about the paper work and bureaucracy, meetings etc. Did you find some way around that?

Kidder: You know the old joke about the bum who is looking for his quarter under the street light, even though he dropped it half a mile away because the light is better. This book doesn't take on, in any detail, the software part of the project which is at least half. There were some things that I saw more of than others. I was also able to drag a certain amount of that information out of Tom. Then one day I said to Tom: "I don't know much about what you've been up to lately," and Tom said, "Oh you noticed."

I always thought that the salient characteristic of this team, which I thought was charming, was that no one ever seemed to take pert charts at all seriously. A nucleus had built computers before and they knew what was required. They knew, I think, that what was required could simply not be embodied in a pert chart.

Q: If you could do this over again, would you fight harder for a mode bit?

West: No, quite the contrary. In hindsight I thought that was a really spectacular decision. Tracy said half the work may have been software where I would guess eighty percent of the work was software. Without the mode bit we could drop sixteen bit programs on that machine and run them. For a long period of time that was exactly what we were doing. We also had three or four hundred thousand lines of diagnostic code, all of which would have had to be rewritten. So for the time being, having that absolute compatability was the only thing that could get it there on time.

The point is that the machine doesn't have a golden moment of when you all of a sudden stop implementing the mode bit and then move on to a different identity Mode bits tend to increase in a geometric fashion, and I've seen a lot of machine families that are now going into their two-to-the-sixth mode bit. Intel is going to solve all their incompatability problems at the chip level with mode bits and it is going to go to huge numbers, I think.

Q: I wonder if you could say something about Ed DeCastro's involvement. The novel makes it seem like he was very rarely checking on the project.

West: That is one of the most difficult questions to answer because once again I think most of the people who were working on the project itself would assume that I had no visibility, barricading myself in my office. Mr. DeCastro is more than likely to let something go with benign neglect, assuming that local management would find a way to solve its problems. He was certainly not involved on a daily or weekly or even monthly basis.

Q: What about Carl Carmen, who was the vice- president of engineering at that time?

West: He was involved during the program, in making sure that the environmental issues were taken care of, that the PC shop worked at the right speed and that things didn't get lost in the mill. He also barricaded the team against the rest of the organization.

Q: Since you weren't able to tell us much about software, those of us who are in software felt a little cheated. Could you tell us what the organization of the software development's side was?

West: When Tracy talked about looking under the street light for the quarter it is because hardware tends to be a lot easier to see, it has a lot more of a visual effect than writing code does.

The reason for having the sixteen bit identity in the machine initially was because we didn't believe that we were going to have any software at all. There was a guy who decided that he could take our existing sixteen bit operating system and by taking it module by module convert it and run it initially in just a couple of the rings with only a couple of the features, and then incrementally get there over a period of a year and a half. He put together a team of twenty volunteers all signing up for a kamikaze mission because nobody really believed that it could be done. Then he decided that we were going to have the software to announce at the same time that we had the hardware to announce. All we had planned to announce was thirtytwo bit hardware, which would get some pressure off our back and point to futures. He managed to do it. The reason that he managed to do it was that he didn't decide okay, I've got a clean sheet of paper and I'm going to develop an O.S. all the way from the ground up, based on the first principles of computer science. The relationship was quite close. In the final analysis, the only thing we really had to de- bug in the thirty-two bit part of the machine was the operating system which had already been run through thirty-two bit simulators. At that stage of the game we were using system software to de-bug the hardware.

Q: What happened to the competing design?

West: The competing design is still alive. It's always difficult to know the answer to "What if?". It would be naive to suppose that D.G. was only working on extensions to the Eagle family of machines. It would also be naive to assume that we are just pragmatically going to follow technology and wander along incrementing the existing product line. The question is when, not whether.

Q: The book mentions a saying in Mr. West's office that anything worth doing is not necessarily worth doing well or something along those lines.

Kidder: One of the things that I began to learn about engineers is that they are aesthetes as much as they pretend to be something else. I've seen this most vividly in the intersection of engineers and non-computer scientists. The engineer talks about technical symmetry and the scientist says I just want something that works. I think that that was what that piece of cryptic puzzling advice was. How did it go? Not everything worth doing is worth doing well.

West: I am very comfortable with that notion. I suspect that there are more people who fail in our industry because they try to do it perfectly, as opposed to doing it on time and on cost.

Q: What are you doing now, respectively, and secondly, are you (Tracy) sick and tired of computers?

West: We are still basically doing the same thing - designing machines - at Data General. The book portrays people leaving, which was true at the time Tracy had to go to press, but since that time a large number of people did stay. All those people have formed a nucleus to build multiple different machines, going in different directions, they build bigger ones, smaller ones, faster and cheaper ones.

Kidder: I'm digging out from under. I'm writing some articles about atmospheric research. To be honest, I'm a little tired of my book. I put it on my shelf and won't read it again for years. I think I know what's wrong with it. In some sense, writing a book is like building a computer. There are rewards but one of the main ones is that Sisyphean one that if you do one you get to do another. So, I have an opportunity now to write a better one.

Extracted from a talk by Tracy Kidder, author of The Soul of a New Machine and Tom West, the chief designer of the machine, Data General's Eagle, in the Museum's "Bits and Bites" series, given October 17th, 1982.

Tracy Kidder autographed copies of The Soul of the New Machine for the Museum. Remaining copies of the autographed copy are available for $18.00 (including shipping) from the Museum store.

Recollections of the Watson Scientific Laboratory, 1945-1950

Herbert Grosch

The heroes of this story are Thomas Watson Sr. and Wallace Eckert. Tom Watson Sr., when I first met him, was in his seventies. In the 20's, 30's and 40's, he supported what he thought of as scientific research, but what we call applied research. At that time, this kind of support was uncommon for even the most advanced American industries.

This famous photograph of Thomas Watson Sr. hung over the fireplace in the Watson Laboratory at Columbia University for which he furnished the money and a large part of the inspiration.

In 1945, IBM remodeled this fraternity house and donated it to Columbia University for the Watson Laboratory. The first concept of the SSEC was formulated in this building and the group that eventually built the NORC (Naval Ordnance Research Calculator) worked on the upper floors and in the basement.

Wallace Eckert's prime life interest was the theory of the motion of the moon. Astronomy provided one of the earliest groups of people who had substantial problems which had to be solved with computation regardless of the form, whether it be pencil and paper, logarithm tables, or with the most advanced modern solid-state computing devices. In the thirties, a major problem was that crossing the Pacific required the measurement of both longitude and latitude. The chronometers were inaccurate and a very accurate clock was needed. Many many years ago the motion of the moon among the stars was suggested as a clock. As a consequence, a great effort was put on the determination of the proper position of the moon. One of Babbage's interests was in building astronomical tables helpful for navigation. Even today, people who are doing algebra on computers, often use the enormously complex and lengthy formulas of the litteral lunar theory as an example.

Eckert discovered a series of articles by L.J. Comrie, a New Zealander who by that time had penetrated the scientific establishment in England sufficiently to become the Director of the Nautical Almanac office at the Royal Greenwich Observatory. These articles explained how Comrie had rented Hollerith machines from the British Tabulating Machine Company and had done the calculation of the positions of the moon for every hour or every six hours or something for hundreds and hundreds of years on a mass production allparallel basis.

Inspired by this, Eckert, with the help of the American Astronomical Society of which he was a junior member and Columbia University where Thomas Watson Sr. was a Trustee, approached the IBM Corporation, a less than one-hundred million dollar business. They donated some special equipment which he installed and called it The Thomas J. Watson Astronomical Computing Bureau which flourished in the late years of the thirties.

Then the War threatened. The U. S. Naval Observatory had to manufacture a new publication called the Air Almanac for the use of navigators crossing the Atlantic by air, especially for bomber navigation, when the skies were clear and bubble sextant observations and so on were possible. They had run out of old-fashioned people who could do this with paper and pencil and logarithm tables. Wallace Eckert's war work was the real McCoy-carrying out very complicated calculations, the sort that strained the professional astronomer. Done, however, in parallel so you didn't have the problem of a complex sequence, but doing a single simple operation to hundreds or thousands of pieces of data at one time and then moving on. With methods he developed for automatic proof-reading, he was able to produce the Air Almanac. Since that time literally millions and millions of characters have been printed by the calculations of such equipment, printed by his automatic printing machine, and proofread by automatic devices without one single error ever having been detected.

In 1941, I became an optical designer which involved lots and lots of calculations on Monroes and Fridens. Then, in the early spring of 1945, an announcement in Science stated that Thomas Watson Sr. had called Wallace Eckert back from Washington and had asked him to establish a new scientific computing laboratory at Columbia University. Before he left Washington, I wrote Wallace asking if I could come around in the evenings and try out some of my ideas on optical design on his nice new shiny IBM machines. One of the incentives for beginning the laboratory was that the computational facilities at Los Alamos had run out of capacity Wallace accepted the charge of setting up a shop of IBM machines at Columbia with the first task to supplement the Los Alamos calculations on the Alamogordo burst. While I only hoped for an invitation to maybe around one night a week, instead a little man from the Manhattan Project showed up at my optical company and took me away. I said, "You know you can't do that, there is no such thing as a civilian draft." He essentially said, "Tell that to General Grove." The next thing I knew I was an IBM employee. In the rush they forgot to pass me through IBM headquarters. As a result, although I received an identification card and all that, nobody had paused to tell me that you could not have hair on your face and work for IBM. So I was not only a very early scientific punch card operator and supervisor but I also was the first bearded sport-coated IBM employee.

1946. Boom. ENIAC. For the first time IBM felt threatened by a development that they had not really foreseen or understood. One of the responses to the ENIAC announcement was the mass production (mass being about twenty units) of the 603 calculating punch operating at around six thousand cards an hour while its electro-mechanical competitors did six hundred. IBM had produced it out of their own patents, their own Eccles-Jordan flip- flops and so forth, originating primarily with a gentleman by the name of Halsey Dickinson. But, this card calculator was not enough for either Eckert or Thomas Watson Sr. who was incensed that someone would produce something that he didn't know about and hadn't sponsored.

A group of people were brought together to write the specifications for a gigantic new machine, the SSEC. With almost no electronic gear available on the market, the arithmetic units were designed around the standard 25L6 radio vacuum tubes. The design of the SSEC went ahead day and night, seven days a week at the IBM engineering laboratory in Endicott. Along with the electronics, a complete panoply of peripheral equipment was designed: high speed card readers, auxiliary tape punches, card punches, fancy console, storage devices, and a major table look up unit in contrast to the setting switches on ENIAC's function table panel.

The whole thing was to be installed in beautiful quarters in the IBM world headquarters at the corner of Madison Avenue and 57th Street, since torn down. Since no sizable ground floor space was available, they bought out a store called the French Bootery around the corner on 57th Street. They tore out the shoe store shelving and put power supplies with a gigantic air- conditioning unit in the basement. The equivalent of false floors was created by a raised floor with the enormous amount of electronic cabling under it. The machine was put together at Endicott, ran, taken apart, and moved to New York City.

On Mr. Watson's final inspection about two or three days before the opening ceremony, he was disturbed by the fact that there were large columns marching down the center of the room. He said, "Everything is lovely you gentlemen have done a beautiful job but I think we should remove those columns." Unfortunately, they held the building up. Nevertheless, the four-color brochure which had been printed for opening day was recalled and a two color sepia print center-fold inserted showing the machine room minus its columns.

After the dedication, Thomas Watson Sr. said, "It's wonderful how these people out at Endicott and these people in New York have slaved over this machine for the last year. Their wives have let them work all hours. They have been diligent and successful. We will celebrate by having a weekend at the Waldorf." On two days notice telegrams went out to all of the senior people that had shared this activity, inviting them and their wives to come to an oldfashioned family get-together at the Waldorf. That is a somewhat large family. Rumor had it that the Waldorf was chosen not only because Mr. Watson liked it very much, but because all bar bills were charged as restaurant. At the luncheon, the old man got up and told us how he loved us, how wonderfully we had behaved, and how we were all part of the IBM family. It was a fantastic exhibition of the kind of excitement that Watson, then in his mid-seventies, could generate.

The Lab's decoration was in my hands and I worked with Mary Noble Smith, the curator of fine arts, who helped me furnish the place with the IBM ceramics and paintings. The ceramics came from a program "the old boy" had sponsored at Syracuse University before the war. He liked it so much that he bought it all and put it in a warehouse where we retrieved some pieces. The old man objected to my choice of French Impressionist paintings in the lobby and remarked that there should be pictures of telescopes and so forth. The next day Mary Noble said, "What are we going to do about those photographs that Mr. Watson wanted?" I said that we weren't going to do anything about it. When they closed the building to move to 115th Street, those paintings were still on the wall. Wallace Eckert was asked for his opinion on paintings of great American scientists commissioned by IBM. Wallace who was a Yale man liked Willard Gibbs, so we hung Willard in the library. Mary Noble came down to me wringing her hands saying, "I don't understand it, we wanted you to have 5 or 6 at least."

I asked to see the list and said, "We will take Ben Franklin."

"But Dr. Grosch," she objected.

I said, "Ben was sort of an amateur natural philosopher, lightning and all that business. But the rest of these guys like the Wright brothers and Edison are inventors, we don't want them here in the Watson Lab."

She said, "I don't understand the difference. What do you mean by a scientist?"

About six weeks later the art van drove up and they delivered a portrait of Newton which I hung in the library with great pride. When I saw her again I asked her where she had found the portrait. She said; "I had it painted fox you."

The SSEC used conventional IBM 405 tabulators rehoused with the tape slugs turned upside down and the wires crossed so as to make it work out of the back instead of the front for the sake of appearance. The 12,000 inch and a quarter diameter 25L6 boggles out of which the arithmetic circuits were made can be seen in the back of the photo.

The SSEC tape drive consisted of a four hundred pound reel of card stock which had to be lifted with a chain hoist. It is sliced, unlike the average roll of card stock, to the length of the punch card rather than to the width. In other words, it is eighty columns wide. It passes through a punch unit in the square box at the upper left and is punched with two round sprocket holes and up to seventy-eight conventional IBM rectangular holes. One line of this punching constitutes a line of instructions or data. It could then go to as many as desired of the succeeding ten stations or loops used as subroutines. Sixteen feet high racks of wire contact relays (equivalent of what we would call core or central memory) were behind the scenes. The electronic memory in the arithmetic unit was only a few words, since the tapes were used as input and longterm memory devices.

The Lab's electronics group was very special. Rex Seeber was recruited from Aiken's Harvard Mark I with the experience of running a big machine which practically no one else in the world had at that time. He was invalu- able as the man who lived downtown with the SSEC in its plate glass and stainless steel palace and turned out very useful work. Eckert was well aware of the fact that IBM did not have modern pulse technology at its disposal. What was needed was to go to the more modern mega-hertz kind of technology which was available in large quantity at Bell Labs and M.LT With the help of I.I. Robie who was Eckert's close friend from his days as an astronomy professor, Eckert hired two young and one mature electronics engineers. They arrived simultaneously and put my nose out of joint because they knew an awful lot of things I hadn't even dreamed of yet. Byhavens built the NORC and was interested from the beginning in doing that kind of activity. John Lenz was more concerned with a tool for individuals and less with building a gigantic machine for number crunching. He built a smaller machine or the pieces of a smaller machine which led toward the IBM 610. Robert Walker, who was the more mature man, first continued to play with analog circuitry and then ended up interested in a simultaneous equation solver.

The Pioneer Computers

Name	Start up	Completion	Program	Word length	Memory size (words)	Add time	Memory type	I/O	Technology	Floor space est. sq. ft.
IBM SSEC 57th Street at Madison, New York City	10/46	1/48	78 hole punched tape (IBM card stock), punched cards, plugboards.	20 decimal digits (19 + sign), double precision, table lookup, 14 x 14 arithmetic	8 words electronic, 150 words relay, 20000 words tape (including 5000 lines of table lookup)	0.3 ms	relays, wide tape	wide tape, punched cards, line printers	12500 vacuum tubes 21400 relays 40000 pluggable connections	3050 (special room)

I mention this because one of his visitors was Clifford Berry, the coworker of Atanasoff. Berry was interested in infra-red spectroscopy and had published an article in The Journal of Applied Physics on a knob-twiddling analog simultaneous equation solver.

Walker wrote to him, had him brought in and they talked with Francis Murphy of the Columbia Math Department and others about how to build a machine of this sort at the Watson Laboratory. By the time it was a useful tool, the technology had moved on towards digital computers. With a 604 you could solve ten equations and ten unknowns to six or eight figures in a reasonable amount of time. In contrast, Walker's analog device took quite a long time to twiddle all the knobs and was less accurate.

The practical computer shop was used by people in chemistry and geophysics at Columbia, by Wallace Eckert, L.H. Thomas, and myself for our research, and for work for General Electric on unclassified nuclear energy and steam turbine design. We helped install the 604's, and watched the CPC develop. We saw people like George Finn, Bill Woodbury and Rex Rice from the aerospace industry demand that IBM build a more sophisticated machine for mass production. Ed Teller especially came to us for calculations in partial differential equations of partial integral differential equations which were tougher than what we had done on the punch card machines. With those we used special relay calculators built for us by Hans Peter Loon who later became head of The Information Society of America. He was a great guy at whomping up special machines using those Lake wire contact relays and his own design methods for survey calculations, cryptography or whatever was needed.

As word spread that a machine was becoming available at the consulting service at Columbia, people began to drift in and say, "Hey, what should I do to start doing this?" In 1948 when I ran the conference at Endicott we were hard put to come up with fifty or sixty people who really wanted to do advanced technical calculation on punch card machines. When the CPC's began to come out and word of the Defense Calculator began to spread there began to be hundreds of installations that became interested in doing it with thousands of people. A.C.M. had started in 1947, the IEEE and its predecessor societies began to talk about applications and not just about the details of construction. There was a time around 1950 when computing went from a small coterie of enthusiasts to being commercially practical. No mass production had occurred: the UNIVAC 1's had not yet been produced; the 701's were still two or three years from major delivery; but the scent was in the air. It was obvious that there were going to be large numbers of sophisticated number crunchers which were going to need trained people, professional operators and software artists. And they were going to be used not only in science and engineering where they were already popular but in business as well.

Yet Wallace always wanted to do astronomy. One of the things we built at the Watson Laboratory was an automatic measuring engine to measure gigantic photographs of the stars. A punch card went in, the machine made a rough setting, a photo-cell made a more accu rate setting and the punch recorded it on the initial card. It sped up the process of astronomical measurement by a factor of five or six. If he had wanted to abandon astronomy and become a computer man, I'm sure he would have been a much better known figure. His contributions were enormous but they were disguised by the fact that he really did them in order to do better astronomy That helped us all, helped astronomy, but it was a direction that did not please IBM so much.

The Watson Lab was very valuable as a consulting service and as a point of contact between IBM and academia. As a part of astronomical research it was unequalled. As a signal that Thomas Watson Sr. who furnished the money and much of the incentive for this was committing his rather small company to a scientific and engineering enterprise that was unfamiliar to it, it was very significant. One of the things that we did was to teach courses in machine operation and numerical analysis. I think that the main thing that it did was to bring a whole bunch of youngsters into the trade. Because of its location at a University, because we offered courses, because we tried to get young people from customer installations to come and take special work on numerical analysis and punch card machine operation, we passed several hundred bright new people through that shop before it moved to physical research. In the long run, the fact that we had Backus, McClelland, and people like that did more good out in the world than just telling GE that yes, they ought to get a defense calculator.

NORC was the pinnacle of achievement of the old Watson Laboratory. Although it wasn't delivered until 1953 or so, the work had gone on from 1948. It was also, in a sense, the culmination of the decimal machine.

Extracted from a Museum Lecture given by Dr. Grosch on October 22, 1982. It provides a complementary, personal view of the Watson Laboratory at the time of the SSEC to the two articles appearing in the October 1982 Annals of the History of Computing: "The SSEC in Historical Perspective" by Charles J. Bashe and "A Large-Scale, GeneralPurpose Electronic Digital CalculatorThe SSEC" by]ohn C. McPherson, Frank E. Hamilton, and Robert R. Seeber, Jr.

As a result of this lecture and the two articles, the Museum's Pioneer Computer Timeline is being revised to include the SSEC: the first machine to combine electronic computation with a stored program and capable of operating on its own instructions as data.

Field Trip to North Bay

(to see a SAGE installation)

Gordon Bell

The high point of the first Computer Museum members' field trip was the visit to the SAGE AN/FSQ-7 computer prior to its decommissioning after operating "around-the- clock" since 1962. The "Q-7", once known as Whirlwind II, grew out of the Whirlwind project at MIT and became the prototype for the nation's air defense systems. In turn, this technology formed the basis of modern air traffic control!

Seventeen museum members made the trip to North Bay, Canada and the National Museum of Science and Technology in Ottawa. The group included Bob Crago from IBM, one of the key designers; Kent Redmond and Tom Smith, historians writing the SAGE story; Henry Tropp, who is writing an article for the Annals of the History of Computing; and Richard Solomon who photographed and videotaped the Q-7 as part of an MIT Project on the History of Computing. We left Friday noon, 8 October, from Bedford, Mass. for North Bay, arrived and visited the "hole" where we were completely briefed by members of the staff and original installation team, had dinner with the Canadian Air Force leaders, including the Commanding NORAD General (U.S.), flew on to Ottawa where we spent the night prior to visiting the National Museum of Science and Technology and returned Saturday afternoon.

The Q-7

Bob Everett's paper on the SAGE computer was published in 'S7, and the machine was operational in Canada in '62. The machine created many patents as by-products, including perhaps the first associative store (using a drum). The machine is duplexed with a warm standby (I mean warm since the duplexed machine uses about 1 Megawatt of power to heat 55,000 tubes, 175,000 diodes and 13,000 transistors in 7,000 plug-ins!). The 6 microsecond, 32-bit word machine has 4 x 64K x 32-bit core memories and about the same memory in twelve 10.7" diameter, 2900 rpm drums, 6 of which are for secondary memory. There is no use of interrupts and I/O is done in an elegant fashion by loading/unloading parallel tracks of the drums with the external world completely in parallel with computing. That is, the I/O state becomes part of the computer's memory state. A single I/O channel is then used to move a drum track to and from the primary core memory.

The main I/O is a scan and height radar that tracks targets and finds their altitude. The operator's radar consoles plot the terrain and targets according to operator switch requests. The computer sends information to be plotted on 20" round Hughes Charactron (vector and alpha gun) tubes or displayed on small alphanumeric storage tubes for supplementary information. Communication lines connect neighboring air defense sectors and the overall command. The operating system of 1 Mword is stored on 728 tape drives and the drums.

The computer logic is stored in many open bays 15' to 30' long, each of which has a bay of voltage marginal check switches on the left side, followed by up to a maximum of 15 panels. The vertical panels are about 7' high by 2' wide and hold about 20 plug-in logic units. The separate right and left half of the arithmetic units are about 30' each or about 2' per bit. Two sets of the AMD 2901 Four-bit Microprocessor Slice would be an overkill for this 32 bit function today. The machine does vector (of length 2) arithmetic to handle the co- ordinate operations. The room with one cpu, drum and memory is about 50' x 150', and the room with two cpu consoles, tapes and card I/O printer is about 25' x 50'. The several dozen radar consoles are in a very large room.

The AN/FSQ-7 control room has been an integral part of the SAGE air defense system from 1962 until powering down in the spring of 1983.

These are only a few of the 55,000 vacuum tubes in replacable plugin modules that support the SAGE AN/FSQ-7 at North Bay, Canada.

Underground Site

The enormity of the machine was dwarfed by the underground building which encloses it. The building hollowed out of stone by hardrock miners is 600' beneath the surface, and connected by a 6000' tunnel which can be sealed off in seconds if there are very large, atmospheric disturbances. The building is about 150,000 square feet and has 10 standby 100 Kw generators and an air conditioner that can operate closed loop into an underground pond.

Cost and Reliability

The machine and software cost about $25M in 1962 and the site about $25M. The facility costs several million to operate per year, including about $1M to IBM. Three people are needed to maintain the software. Initially, one hundred people were used to install the machine and set up its maintenance. When you count the radar, planes, etc. and operational costs, the computer cost is almost an incidental.

The reliability is fantastic! With ONE COMPUTER, AVAILABILITY IS 99.83% and with DUPLEX OPERATION, AVAILABILITY IS 99.97%! Having wondered why such an obsolete computer would be still used, it was clear: the reliability and the overwhelming fixed costs for radar, airplanes, etc. Marginal checking and incredibly conservative design were the key. Each week they regularly replace 300 tubes and an additional 5 tubes that are showing signs of deterioration.

Even though the program is about 1 Mword, written in assembly language and Jovial, the key here is the aging and the fact that the program is NOT interrupt driven. The program simply cycles through the job queue every few seconds in a round robin fashion. This is an excellent example of superb software engineering with an incredibly simple overall structure since it is non-parallel, all the bugs that an interrupt driven system would have had are avoided. Users identify overload by the lengthened cycle time. The high reliability demonstrates learning curves as applied to reliability This obvious notion just occurred to me: since all the software I see is always changing, it doesn't reach ultra-high reliability.

Bottom Line

I doubt if any of the existing personal computers that operate today will either operate or be found in 25 years, simply because technology will have changed so much in performance and reliability as to make them uneconomical at the personal level. How many of us still repair and use our 10 year old HP35's? Furthermore, all the floppies will have worn out and we'll be glad to be rid of them.

Gordon Bell,

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Highlights from

The Computer Museum Report

Volume 5 ---- Summer 1983

Contents of Highlights

ILLIAC IV

R. Michael Hord

The most recent addition to the Museum's Hall of Super Computers is the Illiac IV, an advanced computer designed and developed at the University of Illinois in the mid-1960's by Professor Daniel Slotnick and sponsored by the Defense Advanced Research Projects Agency. On loan from NASA Ames where it was delivered in 1971 and used in computational fluid dynamics research, the Illiac IV exhibit at the Museum includes the central unit, the processing unit cabinet with eight processing units and two Burroughs disks. The following article is excerpted from R. Michael Hord's Illiac IV The First Supercomputer, published in 1982 by the Computer Science Press. The book is available at the Museum store. (Reprinted with permission from the author.)

Project History

It was during the spring of 1970 that the Illiac IV computer project reached its climax. Illiac IV was the culmination of a brilliant parallel computation idea, doggedly pursued by Daniel Slotnick for nearly two decades, from its conception when he was graduate student to its realization in the form of a massive supercomputer. Conceived as a machine to perform a billion operations per second, a speed it was never to achieve, Illiac IV ultimately included more than a million logic gates-by far the largest assemblage of hardware ever in a single machine.

Until 1970, Illiac IV had been a research and development project, whose controversy was limited to the precise debates of computer scientists, the agonizing of system and hardware designers, and the questioning of budget managers. Afterward, the giant machine was to become a more or less practical computational tool, whose disposition would be a matter of achieving the best return on a government investment of more than $31 million.

Illiac IV was funded by the U.S. Department of Defense's Advanced Research Project Agency (ARPA) through the U.S. Air Force Rome Air Defense Center. However, the entire project was not only conceived, but to a large extent managed, by academicians at the University of Illinois. Finally, the system hardware was actually designed and built by manufacturing firmsBurroughs acted as the overall system contractor; key subcontractors included Texas Instruments and Fairchild Semiconductor.

Perhaps the greatest strength of Illiac IV as an R&D project, was in the pressures it mounted to move the computer state of the art forward. There was a conscious decision on the part of all the technical people involved to press the then-existing limits of technology. Dr. Slotnick [. . .] made it clear to his coworkers that the glamour and publicity attendant to building the fastest and biggest machine in the world were necessary to successfully complete what they had started.

Design History

The story of Illiac IV begins in the mid-1960's. Then, as now, the computational community had requirements for machines much faster and with more capacity than were available. Large classes of important calculational problems were outside the realm of practicality because the most powerful machines of the day were 'too slow by orders of magnitude to execute the programs in plausible time. These applications included ballistic missile defense analyses, reactor design calculations, climate modelling, large linear programming, hydrodynamic simulations, seismic data processing and a host of others.

Designers realized that new kinds of logical organization were needed to break through the speed of light barrier [186,000 miles per second] to sequential computers. The response to this need was parallel architecture. It was not the only response. Another architectural approach that met with some success was overlapping or pipelining wherein an assembly line process is set up for performing sequential operations at different stations within the computer in the way an automobile is fabricated. The Illiac IV incorporates both of these architectural features.

The Illiac IV is the fourth in a series of advanced computers from the University of Illinois; its predecessors include a vacuum tube machine completed in 1952 (11,000 operations per second), a transistor machine completed in 1963 (500,000 operations per second) and a 1966 machine designed for automatic scanning of large quantities of visual data. The Illiac IV is a parallel processor in which 64 separate computers work in tandem on the same problem. This parallel approach to computation allows the Illiac IV to achieve up to 300 million operations per second.

The logical design of the Illiac IV is patterned after the Solomon computers. Prototypes of these were built in the early 1960's by the Westinghouse Electric Company. This type of computer architecture is referred to as SIMD, Single Instruction Multiple Datastream. In this design there is a single control processor which sends instructions broadcast style to a multitude of replicated processing units termed elements. Each of these processing elements has an individual memory unit; the control unit transmits addresses to these processing element memories. The processing elements execute the same instruction simultaneously on data that differs in each processing element memory.

In the particular case of the Illiac IV each of the processing element memories has a capacity of 2,048 words of 64 bit length. In aggregate, the processing element memories provide a megabyte of storage. The time required to fetch a number from this memory is 188 nanoseconds, but because additional logic circuitry is needed to resolve contention when two sections of the Illiac N access memory simultaneously, the minimum time between successive operations is somewhat longer.

In the execution of a program it is often necessary to move data or intermediate results from one processor to another. One way of regarding this interconnection pattern is to consider the processing elements as a linear string numbered from 0 to 63. Each processor is provided a direct data path to four other processors, its immediate right and left neighbors and the neighbors spaced eight elements away. So, for example, processor 10 is directly connected to processors 9, 11, 2, and 18. This interconnection structure is wrapped around, so processor 63 is directly connected to processor 0.

Illiac IV functional diagram.

This routing diagram shows schematically the neighbor-to-neighbor linkages which form the 64 processing elements (PE) into a ring, as well as the connections of the PE's eight apart such that data can bypass intermediate PE's when the distance to be covered is large.

The other major control feature that characterizes the Illiac N is the enable/ disable function. While it's true that the 64 processing elements are under centralized control, each of the processing elements has some degree of individual control [provided] by a mode value. For a given processor [it] is either 1 or 0, corresponding to the processor being enabled "on" or disabled "off". The 64 mode values can be set independently under program control, depending on the different data values unique to each processing element. Enabled processors respond to commands from the control unit; disabled elements respond only to a command to change mode. Mode values can be set on specific conditions encountered during program execution. For example, the contents of two registers can be compared and the mode value can be set on the outcome of the comparison. Hence iterative calculations can be terminated in some processors while the iteration continues in others, when, say, a quantity exceeded a specific numerical limit.

In addition to the megabyte of processor element memory, the Illiac IV has a main memory with a sixteen million word capacity. This main memory is implemented in magnetic rotating disks. Thirteen fixed head disks in synchronized rotation are organized into 52 bands of 300 pages each (an Illiac page is 1,024 words). This billion- bit storage subsystem is termed the Illiac IV Disk Memory or 14DM. The access time is determined by the rotation rate of the disks. Each disk rotates once in 40 milliseconds so the average access time is 20 milliseconds. This latency makes the access time about 100,000 times longer than the access time for processor element memory. The transfer rate, however, is 500 million bits per second.

This memory subsystem, the input/ output peripherals and the management of the other parts of the system [were] under the direction of a Digital Equipment Corporation PDP-10 conventional computer. A Burroughs B-6700 computer compiles the programs submitted to the Illiac into machine language.

This Burroughs Disk exhibited at The Computer Museum is only one of the thirteen synchronously rotating fixed head disks that comprised the 16M word main memory of Illiac IV.

Circuitry

Initial plans for Illiac IV circuitry envisioned bipolar emitter-coupled logic (ECL) gates capable of speeds of the order of 2-3 ns. The ECL circuits were to be packaged with 20 gates per chipa level of complexity that later would be called medium scale integration. [Texas Instruments was chosen as the subcontractor for these circuits.] Illiac IV initial specifications called for a 2,048-word, 64- bits-per-word, 240-ns cycle time memory for each of its processing elements. In 1966, the only technology that seemed to meet the requirements was the thinfilm memory. At that time, a few developmental semiconductor memory chips were being studied, but no computer manufacturer would yet consider them seriously for main memory use.

[However, a change] to smaller ECL circuit chips proved a death blow to thin-film memory. When the smaller chips' requirements for added space on circuit boards and interconnections were taken into account, it turned out that there was not enough room for the smallest feasible thin- film memory configuration. Strangely, the failures of the ECL circuits and thin-film memories also set the stage for a brilliant hardware success: Illiac IV was to be one of the first computers to use all semiconductor main memories. Slotnick chose Fairchild as the semiconductor memory subcontractor.

Called for were 2,048 words (64 bits/ word) of memory for each of the 64 Illiac processing elements, a total of 131,072 bits per processing element. The memory was to operate with a cycle time of 240 ns and access time of 120 ns. Slotnick recalls the development proudly: "I was the first user of semiconductor memories, [and] Illiac IV was the first machine to have all-semiconductor memories. Fairchild did a magnificent job of pulling our chestnuts out of the fire [. . .] the memories were superb and their reliability to this day is just incredibly good."

Results

The end results this pioneering [project] had on computer hardware were impressive: Illiac IV was one of the first computers to use all semiconductor main memories; the project also helped to make faster and more highly integrated bipolar logic circuits available; in a negative but decisive sense, Illiac IV gave a death blow to thin- film memories; the physical design, using large, 15-layer printed circuit boards, challenged the capabilities of automated design techniques.

Installing the Illiac IV

Jay Patton

Jay Patton, Manager of Installation Planning at Burroughs Corporation, coordinated the initial set up of the Illiac IV at NASA Ames in 1970 and came to the Computer Museum in December to reinstall it. Comments made during his gallery talk follow, conveying an idea of the massive size of the computer and its capabilities.

"In 1970, ARPA (Advanced Research Project Agency) determined that the Illiac IV parallel architecture could best be tested in an environment that had research programs requiring the potential power of the machine. A new wing was built to house Illiac IV It took one month to disassemble the unit from our testbed in Paoli, which had 100 tons of air conditioning built into it. The computer totalled 53' in length, and took 11 40' vans to house it, weighing 99 tons. One truck alone had only power supplies in it.

Illiac IV had a total of 11,739 pc boards. You can imagine what the spares problem was, and projecting what the failure rate would be. There was a group of people who did nothing but work on equations such as the mean time between failure rate. Inside each pc board were 12 layers of pc material. Each of the boards is coded with a letter code at the top, and a number code at the bottom. You cannot physically put a wrong board in the wrong spot.

From the control unit to each one of the processing extenders (which is a separate computer all in itself) there were belted cables in the back running the length-in one unit alone, there's over 85 miles of cable. The cooling air was 45,000 cubic feet of air per minute. It used over a half a megawatt of power. When we turned it on, we had to do it by sections, not all at once.

The disk system had a transfer rate of 500 x 106 bits per second, when you had two disks running in parallel. The parallel concept for Illiac was used to bypass the speed of light limitation, because you could do 64 additions, subtractions, or multiplications simultaneously. The maximum speed intended by the design was 200 x 106 operations per second; it actually achieved an effective speed of over 60 million instructions per second on some applications.

You can imagine the traumatic experience I had when I compared the 1970 National Geographic photograph of the Illiac IV and the recent National Geographic (October 1982) photograph of Illiac being torn apart and having an autopsy done on it. Then you can imagine how I felt when a call came from Marcie Smith [NASA Ames] to tell me that the Computer Museum was going to ask me to help put Illiac back together - she asked me to control my laughter. The computer really was the dinosaur of the sixties. What you see in the museum are the skeletal remains of a once-proud unit."

Collecting, Exhibiting and Archiving

The Exhibits and Archives department rarely refuses donations offered expand the collection. With computing technology changing so rapidly, determining the future significance of a piece is difficult. To turn away a potential acquisition because it seems less important hinders the future growth of the collection. The collection now numbers about 450 pieces, representing the largest holding of computer artifacts anywhere.

As the Museum has evolved, it has established a close relationship with its members and friends-engineers, computer scientists and history buffs -who are responsible for many donations. Often they refer the department to an available artifact, or make a donation from their own collections. When an object is offered to the collection, they act as curators, illuminating the importance of the acquisition, and sometimes preparing text for an exhibit. While not actually employed by the Museum, they act in its behalf as the experts in computing technology.

The collections policy outlines the process of acquiring artifacts. A deaccessioning clause clarifies to donors at the piece they donate today may not always be part of the permanent collection for reasons of space, a lessening of historical value, or duplication. The deaccessioning policy contributes to our habitual "squirrelling" of artifacts; the donor has agreed that the piece may be taken off the catalog listing and traded with another Museum for another piece, or its parts, if it is a duplicate, could be sold to other collectors through the Museum store. Very little is ever scrapped.

After determining the significance of an acquisition, the artifact is pursued. Most acquisitions require a little detective work and some phone calls to ensure shipment, while a few others are more elusive. In June of 1981, Greg Mellen from Univac in St. Paul called to say he had located a part of the 1956 NTDS (Naval Tactical Data System) in an office in St. Paul. Seymour Cray was the director of development for the NTDS project, the first automated command and control system within the Navy. Initial letters were mailed and calls made to guarantee the CP-642's release to the Museum. It was not until June of 1982 that the paperwork arrived in a large package from the Navy. In order to clear the CP-642, the Navy needed several letters of intent and background from the Museum, all of which had to be notarized, establishing ourselves as a reputable agency for the preservation of computing history. Another six months later, after several follow-up calls, the Navy wrote that they needed a statement from the state of Massachusetts that the Museum was, indeed, tax exempt. In January, 1983, the Navy informed us that the CP-642 was in an office in St. Paul, presumably not due to be shipped until April, 1983, almost two full years after the process started.

When an acquisition arrives at the Museum, it is checked for damage and suitability for immediate display (this usually involves climbing through 40 foot trucks, removing quilted covers and making some on-the-spot decisions). When the nine tons of Illiac IV arrived completely disassembled on the shipping dock-with no Illiac IV experts available in Marlboro-most of the machine, with the exception of the skeleton and several processing units, was sent to storage. Through a contact at NASA Ames, we located Jay Patton at Burroughs, who had originally installed the computer at NASA. Jay spent two days at the Museum, retrieving what had been mistakenly shipped away, and piecing Illiac back together.

A sequential identification number is assigned, with the last two digits representing the year of the donation. Each artifact is catalogued by manufacturer, serial number, physical description, date, and place in computing history, donor name and address, special characteristics, and a brief explanation of the artifact. It is cross referenced to its archival documentation if any exists. An acknowledgement letter, collections policy and receipt for tax purposes are sent to the donor for his records.

The Museum's archives and library began with active solicitation of documentation of collected machines. The understanding was that original manuals would be worthwhile research materials in years to come. This has evolved to the point where relevant photographs, theses, books, films and videotapes are also collected. In collecting archival material, the leads of the Museum's friends and donors are investigated. Contacts for archival material include libraries who wish to donate surplus material from their shelves, and individuals going through personal document collections. On the night of Maurice Wilkes' "Pray, Mr. Babbage" premiere, Mary Hardell donated volume one, number one of the ACM Journal and Bill Luebbert donated a full set of the videotapes from the Los Alamos computer conference. A new acquisition, such as Illiac IV, precipitates outside interest and donations. People who worked on the machine or at the University of Illinois are going through file drawers and attics to collect supplementary materials for us.

This summer's Report lists the whole collection by appropriate categories. Only one-third of the permanent collection is exhibited, with all material that is in storage documented and available for research purposes. As the collection and exhibitions grow, the ratio will probably remain the same. Some parts of the collection are better developed than others, but by looking at what has been collected, it is easier to determine what should be pursued. The collection's growth reflects a new understanding of the importance of preserving computer history, and the many milestones within the computer industry. Active involvement from members, friends and experts in certain areas of computing technology is an invaluable resource in this development.

Jamie Parker
Exhibits and Archives Coordinator

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Highlights from
The Computer Museum Report Fall 1983

Presented here

The Director's Letter

Next fall, The Computer Museum should be operational in downtown Boston at Museum Wharf, a six story condominium for two museums. The Museum will occupy floors five and six. Visitors will enter The Computer Museum via the majestic elevator pictured on the cover. The decision to move was made quickly, but with care.

Last summer, just after we had opened our doors as a public museum, Michael Spock, Director of Boston's Children's Museum and member of The Computer Museum Board, called me and asked, "Would you consider moving to Museum Wharf?"

I retorted, "You've got to be kidding, we just opened in Marlboro." But the seed had been planted.

During the last year, the most common questions from visitors and members were: "In the long run, where do you think the Museum should be?" "How long do you think the Museum will stay in Marlboro?" To be able to respond to these, we evaluated alternative locations that would be convenient to our public: people from around the world interested in computers. Proximity to the airport, convention hotels and local universities were critical factors. The stumbling block was money. Unless a special opportunity arose, relocating would cost tens of millions of dollars and take years of planning.

In January Mike called again and asked if the Museum would consider moving to the top two floors of Museum Wharf. I knew we should take him seriously, but I questioned the suitability of the Wharf space. Having just installed a 9,000 pound section of ILLIAC IV, I asked, "What's the loading capacity of the floor?"

He replied, "One hundred pounds per square foot."

"That's double our present loading capacity," I said. "But, how can we get a 12 x 8 x 4 foot machine to the top floors?"

"No problem," said Spock, "You can drive a fire engine into one end of the elevator and out the other onto the floor."

The location fit the criteria. The site has a canal-front park with a view of downtown Boston. It is minutes from the airport, a short walk from South Station and the "redline" subway that stops near MIT and Harvard, and is convenient to convention hotels. Also, BOSCOM, a permanent international computer marketcenter opening in late 1984 on Commonwealth Pier, is within walking distance.

Exhibit coordinator Jamie Parker and I made an appointment to see the space. The Museum of Transportation had recently moved out leaving a bare shell equipped to hold another museum. The sprinkler system, heating system and public facilities were all up to code. And the structure itself, built as a wool warehouse, had large generic spaces into which exhibits could be set. The Computer Museum could occupy 60,000 square feet, six times more space than it has in Marlboro. While The Computer Museum's goals indicate an eventual need for several hundred thousand square feet, Museum Wharf provides the appropriate next step.

But we did not let ourselves get excited. The Museum didn't have any funds to purchase the property and Mike Spock and the Board of The Children's Museum needed to have a rapid decision. I talked about the issue with Ken Olsen, Chairman of our Board. He in turn took the issue to the officers of Digital Equipment Corporation. The consensus was that if the building provided good value for the Museum, and if enough support would be forthcoming, then it was appropriate to make the move. Digital had been happy to provide an incubator for the Museum, and would be proud to have it move to proper museum quarters at the right time.

Two studies were undertaken to test whether we should purchase one half interest in Museum Wharf. Digital's real estate department determined the value to be received was very high. For a down payment of $1,200,000 and half interest in a $1,600,000 Industrial Revenue Bond (at 8.5% interest to 1999), The Computer Museum will own half of a 155,000 square-foot building equipped as a museum. This is a third of the cost that most museums have to pay for similar space in similar locations. Simultaneously Robert J. Corcoran Associates undertook a feasibility study to determine whether $5 million could be raised for this project. After more than sixty interviews with industry leaders, they gave the project an unequivocal green light. The Board of Directors of The Computer Museum then agreed to undertake the necessary fundraising to enable this move.

Since then, the staffs of the two museums have met together and started to work on appropriate ways to share and cooperate as the owners of Museum Wharf.

The ground floor of the Wharf will be developed for public spaces. Both museums will have separate lobbies and separate museum shops, accessible to the public without entering the museums. MacDonalds has a long term lease on the bay on one end of the building, and in the summertime "The Milk Bottle" is open as a refreshment stand.

The Children's Museum occupies floors two through four and is accessible by several interior stairways. Unlike many children's museums, it is both collection based and hands-on. The Americana, Native American, and Japanese collections provide the basis for exhibits, study and teacher resource material. The centerpiece of the Japanese collection is a recreated 16th century silk merchant's house from Kyoto. Visitors take off their shoes, sit on tamamis and listen to an interpreter tell about life in the house. The collections and study areas are housed in special climate-controlled areas beyond the house. The curatorial staff of The Children's Museum will help us understand how best to use the Wharf building for exhibits and the interrelation of study, collections and exhibitions-an important concept for The Computer Museum to develop.

This move will bring the Museum to a new threshold in developing exhibits. The members, many who act as "curators," have helped us acquire and interpret the exhibits, resulting in a technical presentation. After an exhibit is up, they comment and criticize, and we make changes. Many visitors at Museum Wharf will be laymen, so our exhibits must be more accurate from the start and must be layered from a general to a technical level. Because member input has been so valuable, the exhibits will open for members only as a field test. If all goes well, next May you will be invited to Museum Wharf to review the first exhibition. And with all that has happened in this past year, I'm betting on it.

Gwen Bell
Director

Creating Archives for the History of Information Processing

Symposium

The Computer Museum sponsored two-day symposium in May on archiving issues in information processing history.

In only 35 years, the Information Revolution has produced more historical records on itself in more forms than those available about any previous scientific era.

Symposium attendees included archivists and others from The MITRE Corporation, Lawrence Livermore Laboratories, Travellers Insurance Company, the MIT Library and Museum, Elecitherian Mills Museum, Clark University, the Charles Babbage Institute, the Annals of the History of Computing, and the National Museum of Science and Technology, Canada.

"Criteria and taxonomies must be established for collections," said Helen Slotkin, archivist at MIT, "The first step is the general taxonomy of the field, such as that provided in Bell and Newell's Computer Structures and adopted by The Computer Museum. The second step is the decision of whether or not to save any particular document." ,

Slotkin emphasized that a ' record" is a record" independent of the field, and contemporary standard archival criteria for preservation may be used. But contemporary standards are different from those passed down from librarians in the days when everything could be saved, shelved and cataloged.

Gordon Bell and Jean Sammet, both authors of historical "trees," argued about the placement of limbs and branches and agreed that getting the tree planted was the significant point. A forest with a limited number of species for various major collecting areas would then give the overall picture.

The importance of different collections was also discussed. Arthur Norberg, director of the Charles Babbage Institute, described its focus on the early papers of the individuals who formed the industry, and hence the evolution of the information processing industry. Computer Museum archivists explained its collecting policy - the Museum starts with hardware and then collects the accompanying documentation. It was recognized that each institution would provide archives in keeping with its primary role. For example, universities and company archives would be expected to be primary sources for the papers on people and activities primarily associated with them.

Computer historian Paul Ceruzzi made the case that although we need to see documents of all kinds, the artifacts themselves are also valuable. A movie or a set of prints just does not provide the same understanding as the object itself, or even a few pieces of the object; and whenever those have survived they ought to be saved.

The symposium opened with a showing of videotapes and films of information processing, followed by a discussion. The films were grouped into three kinds:

1. "Vintage films" (at least 15 years old) that have been found and considered to be worth saving;
2. Contemporary documentaries made with a historic purpose in mind, which include the commissioned videotapes of The Computer Museum and the video-history program at MIT under the direction of Ithiel de Sola Pool and his assistant, Richard Solomon;
3. Videotaped presentations of lectures and conferences devoted to historic topics.

Video archives create separate archival issues. Videotapes are easy to make and getting less expensive every day, yet they are time consuming to edit, expensive to preserve, and require special equipment to watch.

Martin Campbell-Kelly, a collector of vintage films who uses films in his classes at the University of Warwick, led off the discussion. He suggested that all films and video should be rated. This set the group into discussion.

Jean Sammet: "Outside from the caveat of cost (and I realize that is a big one), I think everything created on film ought to be kept. I want to see expression on people's faces. I suspect that everyone has watched a rocket launch and gotten a thrill from it. It's only a piece of machinery going up in the air.

And so what? Fifty or a hundred years from now school children will watch them and think they are hysterical."

Helen Slotkin: "There were 1,024 rocket launches that were filmed. The national archivist has asked, do we have to keep all of them? There were 150 failures and everyone agrees to keep them."

Richard Solomon: "What would we give for a film of Babbage and Ada Lovelace just chatting, not even saying anything of historical interest?"

Gwen Bell: "We not only have to be concerned with what we save but also what we create."

Helen Slotkin: "An archivist is passive. Only gathers things. In creating records, you are saying there are holes and we will fill them. It is conscious and after-the-fact."

Gordon Bell: "Guidelines are needed for making films, because the Museum commissioned two films of decommissioning of machines; one is great and the other is awful."

Ithiel de Sola Pool: "The important thing is the groups of people and their relationships and how this comes across on videotape. Factual information can be better transferred in other ways."

Helen Slotkin: "Unless you know who the user will be, you can't make the decision about what to save. If you decide to film a conference, it could be used five different ways, and in each case it would be done differently."

Gordon Bell: "Let's only deal with the producer/storey problem, not the consumer problem. Nice to have the Los Alamos tapes and the Museum lecture tapes-in the first case the people were in a group and defending their turf and in the second they were on their own- the star. We need a set of rules of how to cut at the source."

Barbara Costello (Lawrence Livermore Laboratories): "Accuracy in videotapes is relatively difficult; not the same control as books; especially on the made tapes."

Gwen Bell: "At present, for the produced tapes, there is no reviewing system as there is for an article or book. They don't have the same kind of close scrutiny."

The Origin of Spacewar

J. M. Graetz

I. BEFORE SPACEWAR!

The Lensman, The Skylark, and the Hingham Institute

Picture of SpaceWar! on PDP-1 CRT

It's Kimball Kinnison's fault. And Dick Seaton's. Without the Gray Lensman and the **Skylark of Space** there would be nothing to write about. So most of the blame falls on E. E. Smith, but the Toho Film Studios and the American Research and Development Corp. have something to answer for as well. If Doc Smith had been content designing doughnuts, if AmericanInternational Pictures had stuck to beach blanket flicks, if (most of all) General Doriot hadn't waved money in front of Ken Olsen in 1957, the world might yet be free of **Spacewar!**

It all came together in 1961 at the Hingham Institute, a barely habitable tenement on Hingham Street in Cambridge, MA. Three Institute

Fellows were involved: Wayne Wiitanen, mathematician, early music buff, and mountain climber; J. Martin Graetz (which is me), man of no fixed talent who tended to act superior because he was already a Published Author; and Stephen R. (Slug) Russell, specialist in steam trains, trivia, and artificial intelligence. We were all about 25 (the more or less to be the same).

At the time, we were crashing and banging our way through the "Skylark" and "Lensman" novels of Edward E. Smith, PhD, a cereal chemist who wrote with the grace and refinement of a pneumatic drill.

In a pinch, which is where they usually were, our heroes could be counted on to come up with a complete scientific theory, invent the technology to implement it, build the tools to implement the technology, and produce the (usually) weapons to blow away the baddies, all while being chased in their spaceship hither and thither throughout the trackless wastes of the galaxy (he wrote like that) by assorted Fenachrone, Boskonians, and the World Steel Corporation.

In breaks between books, we would be off to one of Boston's seedier cinemas to view the latest trash from ???. These movies depended for their effects on high quality modelwork, oceans of rays, beams, explosions and general brouhaha, and the determined avoidance of plot, character, or significance. They were the movie equivalent of **The Skylark of Space.**

If that's the case, we asked ourselves, why doesn't anyone make Skylark movies? Hearing no reply (our innocence of current film technology, economics, and copyright laws was enormous), we often passed the time in the Hingham Street common room in deep wishful thought, inventing special effects and sequences for a grand series of space epics that would never see a sound stage. Nonetheless, these books, movies, and bull-sessions established the mind-set that eventually led to **Spacewar!**

When Computers Were Gods

In early 1961 Wayne, Slug, and I, by no coincidence, were all working at Harvard University's Littauer Statistical Laboratory. A large part of our jobs was to run statistics computations on an IBM 704.

To a generation whose concept of a computer is founded on the Z80 chip, it may be hard to visualize a 704 or to comprehend the place it held in the public imagination. It was a collection of mysterious hulking gray cabinets approachable only through the intercession of The Operator.

Everything about the 704, from the inscrutable main frame to the glowing tubes in the glass-walled core memory case, proclaimed that this was a Very Complicated System operated only by Specially Trained Personnel, among whom programmers and other ordinary mortals were not numbered. In short, a computer was something that you simply did not sit down and fool around with.

A Stone's Throw From Olympus

In the summer of 1961 I went to work for Professor Jack B. Dennis, who was then the proprietor of the TX-O, a machine that to me was only slightly less legendary than its ancestor, Whirlwind. The TX-O was transistorized, and while solid-state computers were beginning to appear on the market, the "Tixo" was the original. Even in 1961 it was acknowledged to be a historically important research facility; many of the programs developed on the TX-O, such as Jack Dennis's MACRO Assembler and Thomas Stockham's FLIT debugging program, were the first of their kind. So the chance to work on this computer was in many ways a rite of passage; it meant that I had joined the ranks of the Real Programmers.

While hardly your average populist Apple, the TX-CS was definitely a step away from the Computer-As-Apollo. Instead of being sealed into its own special chapel, it sat at one end of a typical large, messy MIT research space: With its racks of exposed circuitry, power supplies and meters, and its long, low L-shaped console, the TX-O looked for all the world like the control room of a suburban pumping station. And the thing of it was, you were expected to **run it yourself**.

The TX-O's input and output medium was a Flexowriter: an all- inone keyboard, printer, paper-tape reader and punch, that worked like a mule and had a personality to match. There was also a "high-speed" paper tape reader, a Grand Prix whiz that could read programs into memory almost as fast as the cassette-tape reader on a TRS-80.

And the TX-O had a scope. Console-mounted, programmable CRTs were not unheard of at that time but they were generally slow, inflexible, and awkward to program. The TX-O scope, on the other hand, was easy to use; you could generate a useful display with fewer than a dozen instructions. And if that weren't enough, there was a magic wand: the light pen.

That was the TX-O: the world's first on-line computer, and the training ground for the designers and programmers of later generations of hands-on machines. The first computer bums- hackers-were the products of this training; without it, and them, there would have been no **Spacewar!**

Tixo's People

The users of the TX-O were a melange of students, staff researchers and professors with not much in common other than their need for large amounts of largely unstructured computer time. The feel of the place, however, was established by the hackers-mostly students, but including a professor or two-whose lives seemed to be organized in 18-bit strings.

Out of this cloud of computer bums emerged the group that brought **Spacewar!** to the silver (well, light gray) screen: Dan Edwards (AI Group), LISP specialist; Alan Kotok (TX-O staff), who wrote the MIDAS Debugger; Robert A. Saunders (TX-O staff), who wrote MIDAS, the successor to MACRO; Peter Samson (AI Group), who made the Tixo and PDP-1 play Bach, and Steve Russell and I.

"You Mean That's All It Does?"

When computers were still marvels, people would flock to watch them at work whenever the opportunity arose. They were usually disappointed. Whirring tapes and clattering card readers can hold one's interest only so long. They just did the same dull thing over and over.

On the other hand, something is always happening on a TV screen, which is why people stare at them for hours. On MIT's annual Open House day, for example, people came to stare for hours at Whirlwind's CRT screen. What did they stare at? Bouncing Ball.

Bouncing Ball may be the very first computer-CRT demonstration program. It didn't do much: a dot appeared at the top of the screen, fell to the bottom and bounced (with a "thok" from the console speaker). It bounced off the sides and floor of the displayed box, gradually losing momentum until it hit the floor and rolled off the screen through a hole in the bottom line. And that's all. Pong was not even an idea in 1960. (Note: Well, maybe not Pong, but something very much like it. Watch these pages. -DHA)

The TX-O's counterpart to Bouncing Ball was the Mouse in the Maze, written by Douglas T Ross and John E. Ward. Essentially, it was a short cartoon; a stylized mouse searched through a rectangular maze until it found a piece of cheese which it then ate, leaving a few crumbs. You constructed the maze and placed the cheese (or cheeses-you could have more than one) with the light pen. A variation replaced the cheese with a martini; after drinking the first one the mouse would stagger to the next.

Besides the Mouse, the TX-O also had HAX, which displayed changing patterns according to the settings of two console switch registers. Wellchosen settings could produce interesting shapes or arrangements of dots, sometimes accompanied by amusing sounds from the console speaker. The console speaker is a phenomenon whose day seems to have passed. (More than just a plaything, for the experienced operator the speaker was a valuable guide to the condition of a running program.)

Finally, there was the inevitable Tic-Tac-Toe, with the user playing the computer. The TX-O version used the Flexowriter rather than the scope. (The game is so simple to analyze that there was even a version for the off-line Flexo.)

These four programs pointed the way. Bouncing Ball was a pure demonstration: you pushed the button, and it did all the rest. The mouse was more fun, because you could make it different every time. HAX was a real toy; you could play with it while it was running and make it change on the fly. And TicTac-Toe was an actual game, however simpleminded. The ingredients were there; we just needed an idea.

The World's First Toy Computer

For all its homeliness, the TX-O was still very much a god. It took up lots of space, it had to be carefully tended, it took special procedures to start it up and shut it down, and it cost a lot of money to build. All this changed in the fall of 1961, when the first production-model PDP-1 was installed in the "Kluge Room" next door to the TX-O. It had been anticipated for months; an early brochure announcing the machine (as well as a couple of noshows called the PDP-2 and PDP-3, in case you were wondering about that) had been circulating in the area for a while. It was clear that the PDP-1 had TX-O genes; the hackers would be right at home.

The -1 would be faster than the Tixo, more compact and available. It was the first computer that did not require one to have an E.E. degree and the patience of Buddha to start it up in the morning; you could turn it on anytime by flipping one switch, and when you were finished, you could turn it off. We had never seen anything like that before.

II. SPACEWAR! BEGUN

The Hingham Institute Study Group On Space Warfare

Long before the PDP-1 was up and running, Wayne, Slug and I had formed an ad-hoc committee on what to do with the Type 30 Precision CRT Display which was scheduled to be installed a couple of months after the computer itself. It was clear from the start that while the Ball and Mouse and HAX were clever and amusing, they really weren't very good as demonstration programs. Zooming across the galaxy with our Bergenholm Intertialess Drive, the Hingham Institute Study Group on Space Warfare devised its Theory of Computer Toys. A good demonstration program ought to satisfy three criteria:

1. It should demonstrate, that is, it should show off as many of the computer's resources as possible, and tax those resources to the limit.

2. Within a consistent framework, it should be interesting, which means that every run should be different.

3. It should involve the onlooker in a pleasurable and active way-in short, it should be a game.

With the Fenachrone hot on our ion track, Wayne said, "Look, you need action and you need some kind of skill level. It should be a game where you have to control things moving around on the scope, like, oh, spaceships. Something like an explorer game, or a race or contest . . . a flight, maybe?"

"SPACEWAR!" shouted Slug and I, as the last force screen flared into the violet and went down.

The basic rules developed quickly There would be at least two spaceships, each controlled by a set of console switches ("Gee, it would be neat to have a joystick or something like that . . ."). The ships would have a supply of rocket fuel and some sort of weapon; a ray or a beam, possibly a missile. For really hopeless situations, a panic button would be nice . . . hmmm . . . aha! Hyperspace! (What else, after all, is there?) And that, pretty much, was that.

The Hackers Meet SPACEWAR!

By the end of summer, 1961, Steve Russell had returned to the Artificial Intelligence Group (he'd worked there before Littauer); consequently, what ever ideas the Study Group came up with were soon circulating among the hackers. **Spacewar!** was an appealing, simple concept, and the hackers were the appealingly simple people to bring it to life. First, however, there was the small matter of software.

The PDP-1 was a no-frills machine at the beginning; except for a few diagnostic and utility routines, there was no program library. In a way this suited the hackers just fine; here was a chance both to improve on TX-O software and to write new stuff that couldn't have been done before. First, and fairly quickly, MACRO and FLIT and translated from TXish to PDPese, FLIT becoming the first in a continuing line of DDT on-line debugging programs, Steve Piner PDP-1 wrote a text display and editing program called Expensive Typewriter.

With the software taken care of we could write real programs, which is to say toys. Bouncing Ball was successfully converted to PDP-1 use, but HAX for some reason, was not. But no one really missed it, because we had a brand-new toy invented by Professor Marvin Minsky. The program displayed three dots which proceeded to "interact," weaving various patterns on the scope face. As with HAX, the initializing constants were set in the console switches. Among the patterns were geometric displays, Lissajouslike figures, and "fireworks." Minsky's program title was something like "TriPos: Three- Position Display" but from the beginning we never called it anything but The Minskytron. ("tron" was the In suffix of the early 1960s.)

First Steps

By the end of 1961, all the elements were in place, a brand new, available computer, a cloud of hackers, tolerant when not actively implicated employers, and an exciting idea. Slug Russell was getting the heat from everyone to "do something" about Spacewar! (I was in a different department at MIT by this time and Wayne, alas, was one of those unlucky Army Reservists called to active duty during the Berlin Wall panic in October. He never got to participate in developing his own idea.)

Russell, never one to "do something" when there was an alternative, begged off for one reason or another. One of the excuses for not doing it, Slug remembers, was "Oh, we don't know how to write a sine-cosine routine . . ." Then Alan Kotok came back from a trip all the way to Maynard (DEC headquarters) with paper tapes saying "All right, Russell, here's a sine-cosine routine; now what's your excuse?" "Well," says Slug, "I looked around and I didn't find an excuse, so I had to settle down and do some figuring."

With the heavy mathematics in hand, Slug produced the first objectin-motion program in January 1962. This was nothing more than a dot which could accelerate and change direction under switch control. Even without a hardware multiply-divide capability (on the early PDP-1s, anything stiffer than integer addition and subtraction had to be done by subroutine) the computer was clearly not being pushed.

From dot to rocket ship was a surprisingly easy step. "I realized" Slug says, "that I didn't have to worry about the speed of the sine-cosine routine, because there were only two angles involved in each frame-one for each ship. Then the idea of rotating the grid came out." The ship outlines were represented as a series of direction codes starting from the nose of the ship; when the ship was vertical and taildown, each code digit pointed to one of the five possible adjacent dots that could be displayed next. To display the ship at an angle, Russell calculated the appropriate sine and cosine and added them to the original direction code constants, in effect rotating the entire grid. With this method, the ship's angle had to be calculated only once in each display frame. The outline codes were kept in a table so that different shapes could be tried out at will, but this meant that the table had to be searched every frame to generate the outline. As the game developed, this arrangement proved to be a sticking point which, as we shall see, was neatly solved by Dan Edwards.

By February, the first game was operating. It was a barebones model; just the two ships, a supply of fuel, and a store of "torpedoes"-points of light fired from the nose of the ship. Once launched, a torpedo was a ballistic missile, zooming along until it either hit something (more precisely, until it got within a minimum distance of a ship or another torpedo) or its "time fuse" caused it to self-destruct.

The classic needle and wedge ship outlines and the opposite-quadrant starting positions were established at this stage, as shown in Figure 1. Acceleration was realistic; it took time to get off the mark, and to slow down you had to reverse the ship and blast in the other direction; the rocket exhaust was a flickering "fiery tail."

Rotation, on the other hand, was by something we called "gyros"-a sort of flywheel effect invented to avoid consideration of messy things like moments of inertia. I guess they were really rotational Bergenholms.

It was apparent almost immediately that the featureless background was a liability: It was hard to gauge relative motion; you couldn't tell if the ships were drifting apart or together when they were moving slowly. What we needed, obviously, were some stars. Russell wrote in a random display of dots and the quality of play improved. The only thing left, we thought, was hyperspace, and that was on the way: In fact, we'd just begun.

III. SPACEWAR! COMPLETE

Please keep in mind that what follows did not happen in a neat first-onething-and- then-the-next progression, but rather all at once in a period of about six weeks. When hackers are aroused, anything that can happen will.

The Control Boxes

Spacewar! worked perfectly well from the test word switches on the console, except that the CRT was off to one side, so one player had a visual advantage. More to the point, with two excitable space warriors, jammed into a space meant for one reasonably calm operator, damage to the equipment was a constant threat. At the very least, a jittery player could miss the torpedo switch and hit the start lever, obliterating the universe in one big anti- bang. A separate control device was obviously necessary, but joysticks (our original idea) were not readily available in 1962. So Alan Kotok and Robert A. Saunders, who just happened to be members of the Tech Model Railroad Club, trundled off to the TMRC room, scrabbled around the layout for a while to find odd bits of wood, wire, Bakelite, and switchboard hardware, and when the hammering and sawing and soldering had ceased, there on the CRT table were the first Spacewar! control boxes (Figure 2. These boxes have long since disappeared, but the sketch is a reasonably accurate reconstruction).

The box is wood with a Bakelite top. The two switches are doublethrow; the button is a silent momentary switch. Their functions are as follows:

a. Rotation control. It is pushed to the left to rotate the ship counterclockwise, to the right to rotate clockwise.
b. A two-function control. Pulled back, it is the rocket accelerator; the rocket continues to blast as long as the switch is thrown. Pushed forward, the switch is the hyperspace control, as described below.
c. The torpedo button. It had to be silent so that your opponent could not tell when you were trying to fire. (There was a fixed delay be- tween shots "to allow the torp tubes to cool" and fire was not automatic; you had to keep push- ing the button to get off a missile.)

With the control boxes players could sit comfortably apart, each with a clear view of the screen. That, plus the carefully designed layout of the controls, improved one's playing skills considerably; making the game even more fun.

The Stars of the Heavens

One of the forces driving the dedicated hacker is the quest for elegance. It is not sufficient to write programs that work. They must also be "elegant," either in code or in functionboth, if possible. An elegant program does its job as fast as possible, or is as compact as possible, or is as clever as possible in taking advantage of the particular features of the machine in which it runs, and (finally) produces its results in an esthetically pleasing form without compromising either the results or operation of the other programs associated with it. "Peter Samson," recalls Russell, "was offended by my random stars." In other words, while a background of miscellaneous points of light might be all very well for some run-down jerkwater space fleet, it just wouldn't do for the Galactic Patrol. So Peter Samson sat down and wrote "Expensive Planetarium."

Using data from The American Ephemeris and Nautical Almanac, Samson encoded the entire night (down to just above fifth magnitude between 221/a degrees N and 22'/z degrees S, thus including most of the familiar constellations. The display can remain fixed or move gradually from right to left, ultimately displaying the entire cylinder of stars. The elegance does not stop there. By firing each displayed point the appropriate number of times, Samson was able to produce a display that showed the stars at something close to their actual relative brightness. An attractive demonstration program in its own right, E.P was "duly admired and inhaled into Spacewar!"

The Heavy Star

Up to this point, Spacewar! was heavily biased towards motor skills and fast reflexes, with strategy counting for very little. Games tended to become nothing more than wild shootouts, which was exciting but ultimately unrewarding. Some sort of equalizer was called for.

Russell: "Dan Edwards was offended by the plain spaceships, and felt that gravity should be introduce, pleaded innocence of numerical analysis and other things"-in other words, here's the whitewash brush and there's a section of fence-"so Dan put in the gravity calculations."

The star blazed forth from the center of the screen, its flashing rays a clear warning that it was not to be trifled with. Its gravity well encompassed all space; no matter where you were, if you did not move you would be drawn into the sun and destroyed. (As a gesture of good will towards less skillful or beginning players, a switch option turned annihilation into a sort of hyperspatial translation to the "antipoint," i.e., the four corners of the screen.)

The star did two things. It introduced a player-independent element that the game needed; when speeds were high and space was filled with missiles, it was often sheer luck that kept one from crashing into the star. It also brought the other elements of the game into focus by demanding strategy. In the presence of gravity b ships were affected by something yond their control, but which a skillfully player could use to advantage.

The first result of this new attention to strategy was the opening move in Figure 3, which was quickly dubbed the "CBS opening" because of its eye like shape. It took a while to learn this maneuver but it soon became the Stan dard opening among experienced players, as it generally produced the most exciting games.

The addition of gravity pushed Spacewarl over the edge of flicker-free display. To get back under the lim it, Dan Edwards devised an elegant fiddle to speed up the outline display routine.

In Russell's original program, the outline tables were examined and in terpreted in every display frame, an essentially redundant operation. Ed wards replaced this procedure with an outline "compiler," which examined the tables at the start of a game and compiled a short program to generate the outline for each ship. This dramati cally reduced calculation time, restor ing the steady display and making room for the last of the original bell: and whistles.

Hyperspace

While all this was going on, I was in my secret hideaway (then known a: the Electronic Systems Lab) working on the ultimate panic button; hyper space. The idea was that when every thing else failed you could jump into h e fourth dimension and disappear, this would introduce an element of something very like magic into an otherwise rational universe, the use of hyperspace had to be hedged in some way. Our ultimate goal was a feature that, while useful, was not entirely reliable. The machinery, we said, would be "the Mark One Hyperfield Generators . . . hadn't done a thorough job of testing . . . rushed them to the fleet'" and so on. They'd be good for one or two shots, but would deteriorate rapidly after that. They might not work at all ("It's not my fault, Chewie!") or i1 they did, your chances of coming back out intact were rather less than even. Slug: "It was something you could use, but not something you wanted to use.

The original hyperspace was not that elegant. "MKI unreliability' boiled down to this: you had exactly three jumps. In each jump your ship's co-ordinates were scrambled so that you never knew where you would reappear-it could be in the middle of the sun. You were gone for a discernible period of time, which gave your opponent a bit of a breather, but you came back with your original velocity and direction intact. To jump, you pushed the blast lever forward.

Hyperspace had one cute feature (well, I thought it was cute). Do you remember the Minskytron? One of its displays looked very much like a classical Bohr atom, which in those days was an overworked metaphor for anything to do with space and sciencefiction. Reasoning that a ship entering hyperspace would cause a local distortion of space-time resulting in a warp-induced photonicstress emission (see how easy this is?), I made the disappearing ship leave behind a short Minskytron signature (Figure 4).

Crocks and Loose Ends

In retrospect, it is remarkable that the original Spacewar! managed to include so many features, given the limitations of our PDP-l: 4K words (about 9K bytes) of memory, an instruction cycle time of five microseconds, and a subroutine multiply- divide. It's hardly surprising, then, that we had to let a few unsatisfactory (all right, inelegant) bits go by.

The most irritating of these (and the first to be improved in later versions) was the appropriately-named Crock Explosion. Something dramatic obviously had to happen when a ship was destroyed, but we were dealing with a plain dot-matrix screen. The original control program produced a random-dot burst confined within a small square whose outlines were all too discernible (Figure 5). This explosion was intended merely as a place-holder until something more plausible could be worked out, but after all the other features had been "inhaled," there wasn't room or time for a fancier calculation.

Similarly, the torpedoes were not quite consistent with the Spacewar! universe after the heavy star was in place. The gravity calculations for two ships was as much as the program could handle; there was no time to include half a dozen missiles as well. So the torpedoes were unaffected by the star, with the odd result that you could shoot right through it and hit something on the other side (If you weren't careful getting round the Star, it could be you.). We made the usual excuses . . . mumblemumble photon bombs mumblemumble . . . but no one really cared.

The heavy star itself was not entirely Newtonian. The common tactic of plunging down the gravity well to gain momentum by whipping around the sun (Figure 6) gave you somewhat more energy than you were really entitled to. As this just made the game more interesting, nothing was immediately done to correct it.

IV. AFTER SPACEWAR

The game was essentially complete by the end of April, 1962. The only further immediate work was to make Spacewar! presentable for MIT's annual Science Open House in May. A scoring facility was added so that finite matches could be played, making it easier to limit the time any one person spent at the controls. To provide for the crowds that we (accurately) anticipated, a large screen laboratory CRT was attached to the computer to function as a slave display. Perched on top of a high cabinet, it allowed a roomful of people to watch in relative comfort. Also in May, the first meeting of DECUS (Digital Equipment Computer Users' Society) was held in Bedford, MA. At that meeting I delivered the first paper on the subject, pretentiously titled " Spacewar! Real-Time Capability of the PDP-1."

Over the summer of 1962, the original Spacewar hackers began to drift away. Alan Kotok and I went to work for Digital. Steve Russell followed John McCarthy to Stanford University. Peter Samson and Bob Saunders stayed in Cambridge for a while, but eventually they, too, went west. Dan Edwards remained with the AI group for a few years, then moved to Project MAC, Jack Dennis and the PDP-1 also wound up at Project MAC, which evolved into MIT's Laboratory for Computer Science. Others took up the maintenance and development of Spacewar! Program tapes were already showing up all over the country, not only on PDP-ls but on just about any research computer that had a programmable CRT

A Mystery Just For Good Measure

Slug tells me that there is a Lost Version of Spacewar! There would be, of course. He says the game is pretty much like the original, but the scoring is much more impressive. After each game of a match, cumulative scores are displayed as rows of ships, like a World War II fighter pilot's tally. Slug says he saw this version for a short time on the PDP-1, but never found out who produced it or what became of it.

Twenty Years Later

The original Spacewar PDP-1 was retired in 1975 and put in storage at DEC's Northboro warehouse, where it serves as a parts source for the similar machine now on working display at Digital's Computer Museum in Marlboro, MA. At this writing, DEC engineer Stan Schultz and I are trying to put the original Spacewar! back into operating condition. So far, all attempts at finding the original control boxes have been futile; we will probably build replicas (the plastic Atari joysticks we have now got no class).

Dan Edwards still works for the U.S. Government, developing computer security systems. Alan Kotok is still a consulting engineer with DEC. Peter Samson is now director of marketing for Systems Concepts, Inc., in San Francisco. Bob Saunders had gone to Silicon Valley, where he is an engineer- programmer for HewlettPackard.

Jack Dennis is a Professor of Computer Science at MIT, in the Laboratory thereof.

Marvin Minsky is Dormer Professor of Science in the Electrical Engineering Department at MIT.

John McKenzie, the chief engineer, is retired, but over the past year or so has been helping to restore the TX-O and PDP-1 to life at the Computer Museum.

And what of the Hingham Institute? Wayne Wiitanen has recently become a Senior Research Scientist at the General Motors Research Laboratory, where he is happily designing eyes for robots. Slug, after various adventures, is now a programmeranalyst for Interactive Data Corporation in Waltham, MA. I am reduced to writing for a living, but tend to act somewhat less superior therefor.

Spacewar! itself has bred a race of noisy, garishly-colored monsters that lurk in dark caverns and infest pizza parlors, eating quarters and offering degenerate pleasures. I think I know a few former hackers who aren't the slightest bit surprised.

Acknowledgements

I was able to reach all of the original Spacewar! perpetrators, hackers and Hingham Institute Fellows alike. Not to mention Professors Dennis and Minsky, and John McKenzie. In addition, I am grateful to Marcia Baker, Professor F J. Corbato, and Professor R.M. Fano, all of MIT, for help with dates and places, and other facts. The help was theirs; any mistakes are mine.

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Developing Univac's Plated Thin Film Metal Recording Tape

Ted Bonn, April 17, 1983

While I was at the Moore School of Engineering at The University of Pennsylvania, I took a course with John Mauchly. Then, after I received my Masters degree, Eckert made me an offer. In early September 1947, I climbed to the second floor over a haberdashery in downtown Philadelphia and started to work in the offices and labs of the Eckert-Mauchly Computer Corporation.

Since available acetate base tape materials and magnetic laquer coatings were not good enough, I was assigned to develop plated thin film metal magnetic recording tape for the Universo I. We chose 1/2" wide phosphor bronze tape as the substrate. I knew nothing about plating or magnetic alloys. My starting point was the fact that someone in the Brush Development Company had learned how to electroplate nickel iron permalloy and someone at the Bureau of Standards had learned how to deposit permalloy chemically without current. Since plating was a chemical process I obviously needed a lab with a fume hood, water drains and so forth. One powder room became my lab and the other was left for its intended purpose. The window would be opened to clear out fumes. I would get water out of the sink and the toilet was an ideal drain. Of course, I had to be sure to flush a couple of times when I dumped in acids so that they would not eat the pipes. Being an electrical engineer I would frequently miscalculate the amount of ammonium salts needed and the room would fill with fumes. Then I would throw up the window and stick my head out. But occasionally the door would be opened and the wind would be blowing in the wrong direction, then all Eckert-Mauchly would fill with ammonia fumes.

The chemistry went faster than the electronics. We could deposit a film before we could measure its magnetic properties. We made a piece about three feet long, soldered the ends together to make a loop and mounted it on a loop tester. We tried to record on it. John Mauchly was excited and right at my shoulder. No output. I checked the electronics, and the head, and the write current. Still nothing. Then John remarked that there appeared to be a signal at the joint where the two ends of the tape were soldered. I had seen it too, but it didn't look like a recording signal and I ignored it. John correctly interpreted it as a signal caused by improved magnetic properties due to the heat of soldering. His astute observations started me on a series of experiments on heat treating tape. It was not the final answer, but it was a key answer along the way.

I built a pilot production line and Reed Stovall built and debugged the actual production equipment. The same thin electroplated magnetic film was used by Univac on the LARC drum and on the Fastrand, and many other recording drums and discs throughout the industry. Plated tape was used exclusively with the Univac systems until about 1956 or 1957 when mylar base and epoxy resins became available.

You could see the holes in cards, but we had difficulty convincing some people that there was actually information recorded on the tape, since there is no visible difference between recorded and unrecorded tape. So we made the recording visible. Fine magnetic particles were suspended in a solvent and applied to the tape. The particles were attracted to the magnetic poles and when the solvent evaporated you could clearly see the recorded information. The tracks and the interblock gap stood out. You could pick the pattern up with scotch tape and apply the tape to paper and carry it around to demonstrate.

The design of the tape handler, called "Universo," set the standard for the industry. It featured 100 inch per second tape speed; 120 bits per inch recording density; eight tracks on halfinch wide tape for a data rate of 12,000 characters per second; a start/stop time of 10 milliseconds, this meant the 720 digit block could be recorded in 5.6 inches and the interblock gap was only 2.4 inches long. Thus the Eckert-Mauchly team established magnetic tape as the high speed input/ output medium for computers and designed and successfully produced a complete line of magnetic tape based peripherals.

This narrative explanation given by Ted Bonn at a Sunday Bits and Bites talk corrects misinformation printed in the Summer Report (Page 16) describing the UNIVAC tape.

Captain Grace Hopper on the Harvard Mark I

April 14th, Captain Grace Hopper spoke on her experiences with Commander Howard Aiken and the Harvard Mark 1. The text of this lecture will be incorporated into her contribution to a book on the same sub- ject that is being edited by Professor I. Bernard Cohen.

Speaking to a rapt audience of more than 500 people, Captain Hopper told of her introduction to the machine: "Aiken waved his hand at Mark I, all 51 feet of her, and he said, 'That's a computing engine.' Not a computer. Not a calculator. And there's a difference in the concept that was in his mind as well. Computers are what we have nowadays, black boxes, one unit, one thing. Calculators were those wonderful things you sat on your desk and then you ground out the answer, you moved the register, ground some more. I think when he said computing engine, he was referring to its different parts that took on different functions. That's a concept we've lost that we'll need to bring back again, because we'll be building systems of computers with different functions. He was right when he called Mark I a computing engine; it had many parts that worked simultaneously together with each other and performed functions."

"Howard Aiken was a tough taskmaster. I was sitting at my desk one day and he came up beside me, and I got on my feet real fast. 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 so that I can answer any questions. This is the Mark I manual, the entire bible for Mark I. You could take this and build Mark I again, if anyone felt like it."

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Highlights from
Volume 7, The Computer Museum Report, Winter/1983/84

Contents of Highlights

The Computer Museum is temporarily closed in preparation for its move to Boston. It will reopen at Museum Wharf in downtown Boston in fall 1984. For more information, call (617) 467-4036.

The Director's Letter

The Museum is in a time of change: location, staff and exhibits. But our plan is to keep this Report in its familiar form enabling us to communicate our activities to you. ,

One of the greatest changes has been the departure of Jamie Parker, the Museum's first employee and developer of all the exhibits. She left in August to get married and join her husband in Geneva. In her four years with the Museum, she used her photographic memory to conceptualize exhibits. Jamie had an intuitive feeling for the artifacts and how they could be exhibited even though her education was in art history not computer science. While with the Museum, she cataloged and put three times as much in the warehouse as we had on the floor. One of Jamie's last chores was to organize our yard sale.

The yard sale allowed Jamie to weed our "warehouse." In her first years, she accepted everything because that was her job. The Museum ended up warehousing a number PDP-12s, 338 display systems and PDP-6s. Since Jamie knew what was what and what was best, she selected the items to sell, thus cutting down our storage costs and providing the members with a good day of poking through old junk and taking apart computers. The cover photo is a tribute to Jamie: one of the yard sale customers is carrying off his loot and inspecting the display of the ENIAC, an exhibit put together by her.

A new crew of exhibit and archives employees will help us plan the space for Museum Wharf. Meredith Stelling has taken over as the Coordinator. She has been with the Museum for a year handling publications and archives. Meredith, Greg Welch and Bill Wisheart are the main exhibit staff and will be joined in January by Oliver Strimpel, on leave from The Science Museum in London.

In September, the new space at the Wharf seemed vast and barren, except for chalk marks on the floor indicating where the new exhibits would be positioned. But the space is already beginning to fill out with two truck loads of the SAGE (30,000 pounds), an IBM 1401 card system and a collection from the University of Illinois.

Reviews of exhibit plans started in September. Sheila Grinnel, developer of ASTC's travelling "Chips and Changes" exhibit, Bruce McIntosh, a designer, and Paul Tractman, senior editor, The Smithsonian, spent a day consulting on the proposed organization. Then on October 13th, board members Brian Randell and consultant Dick Eckhouse reviewed the next iteration.

Successive refinements bring our plans in line with reality. The SAGE system will form the fulcrum of the exhibits leading into the computer generations on one floor, and backward in time to the revolutionary one-of-a-kind computers on the other. The process of moving has now started and the enormity of the task ahead is clear. But the team is together and progress can be seen.

Gwen Bell
Director

Harvard Mark III. Magnetic drum storage was pioneered on the Harvard Mark III. the drum rotated at about 3,600 rpm and its randon access time was 17 micro{milli}seconds. By modern standards that was quite slow, however, it was the only way to have moderately priced memory in any quantity in the early 1950s. With its tapes and plugboards the Harvard Mark III covered 40 square feet, and was one of the first hardwired assemblers that transformed mathematical symbols into machine code.

Computers: A Look at the First Generation

In 1955, Martin Weik compiled a "Survey of Domestic Electronic Digital Computing Systems," providing a remarkable snapshot of the computer population. The survey briefly describes and gives specifications for about 100 different machines in existence as of December 1955.

Weik's inventory supplied the base to compile a fundamental reference for collecting and research at The Computer Museum. Records for each machine were gathered from contemporary historical accounts in recent books and journals, operating manuals, and in some cases the machines themselves. Then the findings were checked against those appearing in Weik's original survey.

This research was done by Paul E. Ceruzzi, assistant Professor of History at Clemson University with the aid of Rod McDonald of Rider College, and Greg Welch of The Computer Museum. Different specifications and descriptions have been given to the same machines over time for various reasons. Rather than arbitrarily selecting one description, the data was collected and explained.

These differences occurred for a variety of reasons. Specifications liven in one account often do not agree with those given in another, because a computer's characteristics usually changed from the time of its early design to its final days of operation. The characteristics of some were entered after they had been redesigned and rebuilt, (e.g. SEAC) and others before such redesign (e.g. Johnniac). Nomenclature was also a problem-one manufacturer's "rapid access registers" might be another's "accumulators"these differences were reconciled through research.

Different metrics were often used for speed: the time it took to fetch a number from memory in a drum machine may have been given as the fastest possible, the slowest possible, the average, or the fetch time using optimum coding techniques. A time frame for each machine was established to provide a subjective though reasonable assessment of its historical significance.

The first phase of the survey is complete: the data is stored on disks, and printouts are available for scholars. The next phase is to build the collection, define additional research topics and to develop a very accurate map of computing up to 1955.

Gwen Bell

What did computing look like during its "first generation"-the time from the dedication of ENIAC in 1946 to the mid-fifties?

The variety was astonishing. Experimental one-of-a-kind computers, each with its own unique character, ruled, even though most incorporated vacuum tubes and drum memories, stored programs and data internally, and communicated via Flexowriters.

While most were built with vacuum tubes, many also used relays and crystal diodes.

For memory, they relied on delay lines, cathode ray tubes, drums, magnetic tape loops, paper tape, punched cards, magnetic wire, and toward the end of the period, magnetic cores.

For input and ouput, they used teletypes, punched cards, other paper tape readers, and CRT displays as well as Flexowriters.

Their sizes ranged from that of a small desk to several large rooms full of equipment bays with consoles one could walk into. And their speed ranged from one to tens of thousands of operations per second.

Preliminary Findings: Technology

Most first-generation computers did use vacuum tubes, but not all in the same way. After ENIAC's dedication, designers saw the advantage of tubes for speed, but sought to minimize their number. Those computers used fewer tubes in their circuits, and thus were more reliable and compact. Solid state diodes, not tubes, performed logical operations. This was pioneered in SEAC in 1950, after which only a few computers, such as the Circle and Monrobot, continued to use tubes for logic as ENIAC did.

Between 1946 and 1955, at least a dozen relay computers were built, an indication that some designers did not agree with the prevailing view of the superiority of vacuum tubes. One such person was Howard Aiken, who on visits to Continental Europe in the 1950's influenced the choice of relays for several computers. Konrad Zuse's computer company also produced a line of successful relay computers installed mainly in Continental Europe. Some of the relay computers, like the Bell Labs 5 and 6, were based on se quence calculator designs of a decade earlier. Others, like ERAs "Abel" and the British "ARC," were designed along the lines of stored-program electronic computers, but used relays to save money or to get a prototype working quickly.

By late 1955, a few transistors already were finding their way into computer circuits: in Bell Labs' TRADIC, the IBM 608 Calculator, and perhaps one or two others.

Memory

A wide range of memory devices were used in first-generation computers. None of the mass storage techniques available in the early 1950's was clearly superior; the choice always involved a trade-off of access time versus reliability. This unsettled situation persisted until the end of this period, when the magnetic core memory was perfected.

Drum from the English Electric Deuce. Built in 1957, the Deuce drum stored 8K x 32-bit words on 256 track: of 32 words each. It measured four inches by six inches; most first generation drums were eight to 20 inches in diameter and two to four feet in length. The Deuce drum is on exhibit at The Computer Museum.

The drum was by far the most common memory device. A third of the stored- program computers used it for their primary memory, and most of the others used it for secondary storage. The most popular of the early computers, the IBM 650 with several thousand installations, was a drum machine. A drum is fundamentally an electromechanical device; its reliability, high capacity, and relatively low cost made it the most successful medium.

The designers of the first stored program computers had high hopes for purely electronic, parallel memories. Williams tubes were widely available, but their performance was erratic. Developed in Manchester, England in 1948, they were used on the IBM 701 and in a variant form on the Whirlwind.

John von Neumann, unsatisfied with their reliability, contracted with Jan Rajchman at RCA to produce a electronic, parallel memory, but von Neumann had to make due with Williams tubes on the IAS machine and its offspring in Los Alamos and elsewhere. Finally Jan Rajchman's Selection was completed and installed, but worked well on only one machine, the Johnniac at the Rand Corporation.

SWAC Williams Tube. The Williams tube was invented by Sir Frederick Williams at the University of Manchester in 1948. It was the first purely electronic parallel memory, but it was unreliable. Although magnetic- core memories superseded the Williams tube by 1954, the Williams tube was still faster than drum memory and delay lines. Unlike the earlier version of the Williams tube, the Williams tube from the SWAG (Standards Western Automatic Computer) was more compact and featured higher reliability.
It enabled the calculator from the SWAC to fully utilize the speed of the Williams tube memory by completing arithmetic operations in a few microseconds. Instead of handling numbers as a train of pulses, there were parallel circuits in the SWAC that transfered numbers almost instantly. This transferring of numbers in parallel made it possible to do computations at many times the speed of serial computers. The SWAC was the first Williams tube computer to be completed in the United States. Its rate of success was also dramatic, producing useful results seventy percent of the time. The Williams tube from the SWAC is on exhibit at The Computer Museum.

IBM 650. The IBM 650 was the most widely used first-generation computer. Hundreds were delivered between 1955 and 1959. Although the 650 teas faster than other magnetic drum computers, its high success rate was a result of a well-integrated, punchedcard input and output and its adapt ability to existing punched-card systems.

Huskey Lecture. Harry Huskey giving a lecture next to his Bendix G15 at The Computer Museum in December 1982. He said: "In 1952 and 1953 while at Wayne University (Detroit), 1 dusted off the ideas and designed a computer which the Bendix Corporation elected to build, the Bendix G15. The memory was a magnetic drum with separate read and write heads. All information was read, erased and rewritten every drum rotation just like the mercury delay lines. This gave some technical advantages-the read heads and the write heads could each be optimized for their functions."

Some 15 first-generation computers used mercury delay lines for their main memory. The delay line was more reliable but slower than the Williams tube, while it was less reliable but faster than a drum. The UNIVAC's delay line memory, for example, could access a number in 400 microseconds, compared to 25 microseconds for IAS's Williams tube store, and 2,500 microseconds for the IBM 650 drum. Delay line computers included many historically significant machines: the Cambridge EDSAC, the EDVAC, the SEAC, the Pilot ACE, and the UNIVAC. A few other machines, such as the Pegasus, used magneto-strictive delay lines.

The development of magnetic core memory finally gave computer designers a memory that was reliable, fast and parallel, but expensive at the outset. In 1953, core memories were installed on the Whirlwind computer at MIT and the ENIAC at the Ballistic Research Lab. By 1955, only two commercial computers, the RCA BIZMAC and ERA 1103A, used core memory. Without the new manufacturing technology to build cores, manufacturers of machines based on drums, delay lines, and other devices continued to plan and build these architectures until the price of core fabrication fell.

Harry Huskey, who designed a superior version of the Bendix G15, says: "Bendix made more than four hundred of the G15's- in fact the fittings on number 400 were gold plated. Bendix did plan a transistor version of the G15 but the declining costs of magnetic cores and their improved reliability marked the end of the cyclic memory computers."

Input/Output

Nearly all first-generation computers used a Flexowriter or comparable electronic typewriter with a paper tape reader attached for both input and output. The Flexowriter was simple and rugged, but slow. Photoelectric readers, pioneered on EDSAC and quickly adopted in the United States, read paper tape 20 times faster. A photoelectric reader could input data at 120 characters per second (cps) instead of the six cps that a mechanical reader could handle.

Other computers used punched cards or teletype. The CRT display, so familiar to modern computer users, first appeared on one or two experimental computers like the Whirlwind, and finally on a commercial computer, the ERA 1103, in 1955.

Almost from the beginning of this era, designers recognized the advantages of magnetic tape as a medium for bulk input/output, but tape was slow in being adopted. The use of metallic tape was pioneered on the UNIVAC while the SEAC used magnetic wire mounted in compact cassettes for off-line storage.

Size The smallest stored-program computer was probably one built by Hughes Aircraft for aircraft guidance and control. It measured about two feet by one foot, used a drum memory, and was installed aboard a C-47 airplane in 1953. The largest was perhaps the Whirlwind, which occupied 55,000 square feet. Other large-scale installations that could claim the honor of "biggest" include the IBM 701, the RCA BIZMAC, and the Harvard Mark II, which filled a large room at the Naval Proving Ground in Dahlgreen, Virginia.

Commercial drum computers were generally quite small, ranging in size from that of a small desk to several large cabinets. The cost of development and construction ranged from a few thousand dollars for a prototype Circle Computer (surely the cheapest) to several million for Whirlwind. However, the Whirlwind was more than a single computer, it was an ongoing project involving computers, memories and applications programming.

Architecture

Quite a few computers without a stored- program design were produced and sold into the 1950's. The advantages of the stored program design were slow in being accepted, and many companies built computers of both types. ERA, for example, built a "Logistics Computer" in 1952, which incorporated a fixed program for certain types of problems.

Computer Research Corporation built a general-purpose drum computer, the CRC 102, and also produced the popular CRC 101, a special-purpose machine called a Digital Differential Analyzer. The aircraft industry, a big customer for digital differential analyzers, kept the market alive and several companies were the suppliers. Several externally- programmed drum computers installed in Continental Europe reflected the design of Howard Aiken's Harvard Mark III and Mark IV

Of the stored program computers, about an equal mix handled numbers serially, digit by digit, and in parallel, a word at a time. Similarly, they were equally mixed between binary and decimal machines, with some commercial models like the CRC 102 available either as a binary or a decimal machine.

Core Memory Stack. This core memory stack from the Whirlwind, which is on exhibit at The Computer Museum, measures 17 x 10 x 9 inches. Each core memory plane is arranged in an array of 32 x 32 cores. The first core memories were designed by Jay Forrester for the Whirlwind in 1953 at MIT. Computer access time dropped from twenty-five microseconds for tube storage to nine microseconds for magnetic cores.

A wide range of instruction sets also existed, from CALDIC with only a dozen or so instructions, to the RAYDAC with a four-address code and built-in fixed and floating point instructions. When random access core memory replaced serially-accessed magnetic drums or delay lines, the "von Neumann" architecture of binary arithmetic, single- address instructions, and parallel memory prevailed.

Reports by Burks, Goldstine, and von Neumann on the IAS computer discussed the stored-program principle in detail, especially with regard to modifying the address field of an instruction during a program's execution. Several first- generation computers used special index registers to accomplish the same thing. These were called "B-lines" on the Ferranti Mark I, the first machine to use them, and the name stuck. In the United States, the Consolidated Engineering 30- 201 and its descendents had B-lines. Descriptions of computer architectures nearly always mentioned the stored program in connection with indexing. Some descriptions, including one by Alan Perlis, point out that computers with B- lines were superior in many ways to the simpler IAS design.

Programming

The first generation of computers were programed in machine language, typically by binary digits punched into a paper tape. Activity in higher-level programming was found on both the large-scale machine and on the smaller commercial drum computers.

High-level programming languages have their roots in the mundane. A pressing problem for users of drum computers was placing the program and data on the drum in a way that minimized the waiting time for the computer to fetch them.

It did not take long to realize that the computer could perform the necessary calculations to minimize the so called latency, and out of these routines grew the first rudimentary compilers and interpreters. Indeed, nearly every drum or delay line computer had at least one optimizing compiler. Some of the routines among the serial memory computers include SOAP for the IBM 650, IT for the Datatron, and Magic for the University of Michigan's MIDAC.

Parallel memory machines had less sophisticated and diverse compilers and interpreters. Among the exceptions were SPEEDCODE developed for the IBM 701, JOSS for the Johnniac, and a number of compilers and interpreters for the Whirlwind.

Use

The list of computing installations up to 1955 reveals dominance of the military, followed by laboratory and then business use. In 1954, a Magnefile was installed for inventory control at B. Altman & Co. in New York, and a MODAC 404 was used by Reader's Digest for keeping track of subscriptions, but these were exceptions to the rule.

Installations found at air force or army bases often had not just one, but several computers. Though not a "typical" installation, the Ballistic Research Lab at Aberdeen, Maryland illustrates how military agencies commanded the greater fraction of all computing power in the mid- 1950's. It included: ENIAC; a Bell Labs Model V Relay Computer; EDVAC (a stored program, serial computer); ORDVAC (a stored-program, parallel computer); several digital differential analyzers; punched card multipliers; analog computers; desk calculators, and other computing devices of various shapes and sizes.

Conclusion

The "milestones" of the first generation were brought about by many people who continue to be leaders in the field. Grace Hopper worked on the UNIVAC; Maurice Wilkes on the EDSAC; Joe Weizenbaum and Harry Huskey on the Bendix G-15; Gene Amdahl on his dissertation machine, the WISC; Max Palevsky on the Bendix D-12 Digital Differential Analyzer; An Wang on the Wedilog; Ken Olsen on MIT's memory test computer; and Seymour Cray on the ERA 1103.

Computing was about to change rapidly. In the next few years installations jumped to the thousands. Serially-produced, commerciallymanufactured, standardized machines became the rule. Over the years, experimentation has continued, but never with the diversity of ideas about the basic architecture of this inaugural era.

Paul Ceruzzi, with Rod McDonald and Gregory Welch.

The Core Process: How Ferrite Cores Were Made For Computer Memories

A manufacturing process for core memories was developed by Lincoln Labs in 1952. Core memories were always strung by hand, and production of the first cores was complex and expensive. The following picture story is from the unclassified manual, Ferrite Cores For Computer Memories. These cores were used in the Whirlwind and the Memory Test Computer.

1. **Core Pressing.** After five days of getting the material ready for making cores, core pressing was done automatically by a Stokes press which was capable of 60 pressing operations per minute.

2. **Dimensional Check.** The machine die and the weight of the pressed cores had to be continually monitored to insure maximum uniformity of core size. Before each press run a dimensional check was made with a tool- maker's microscope in order to assure quality control.

3. **Firing.** Firing was the most critical operation of core production. The firing temperature was approximately 2400 F, and elaborate controls were necessary to maintain the correct temperature.

4. **Cooling.** After the cores left the tun- nel of the kiln, they were still at an elevated temperature of 500 F Cooling took place quickly in the open air, and then the cores were ready for counting and electrical testing.

5. **Electrical Testing.** Core drivers helped in electrical core testing. The cores, which were temperature sensitive, were tested at a uniform 25 C. The temperature was controlled by core handlers in temperatureregulated boxes or airconditioned rooms.

6. **Pulse Testing.** A sample of 50 cores from each lot was used for hysteresis-loop measurements. The test equipment for pulse testing and semiautomatic selection testing consisted of an electronic core counter, an evaluation pulse tester, fully automatic and semiautomatic core testers, and a plane tester.

7. **Evaluation Test.** Evaluation pulse testing was performed on a sample of 20 cores. The data obtained from the hysteresis-loop tests and the evaluation pulse tests yielded important information concerning the performance of core lots in a memory. It was at this step where lots could be rejected on the basis of the evaluation test.

8. **Stringing.** After core testing had been completed, the magnetic cores which had been accepted were hand strung into memory planes of 4096 cores each.

9. **Final Test.** The cores in the plane were then given a final pulseresponse test in order insure their acceptability. If damaged, removal of defective cores from a plane was easy at this stage.

10. **Finished Product.** The final operation in the construction of a plane was the insertion of the inhibit winding and sensing wire which linked all the cores in the plane.

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Highlights from

The Computer Museum Report

Volome 8 ---- Spring 1984

Contents of Highlights

The Computer Museum is temporarily closed in preparation for its move to Boston. It will reopen at Museum Wharf in downtown Boston in fall 1984. For more information, call (617) 467-4036.

The Director's Letter

I'm often asked, "Will there be a lot of interactive exhibits in The Computer Museum?"

I don't have a short answer. The long answer compares two exhibits: the TX-0, the first transistorized computer, one of the first computers used for interactive graphics, and a planned exhibition called "The Computer and the Image."

Seeing the TX-0 exhibit-with its banks of switches, bulky Flexowriter, rows of toggle switches, wall of supplies, with its heavy steel chairs with peeling vinyl covers, tile floor and venetian blinds-sends the viewer back to the late fifties. And on days that John McKenzie, with his dapper bow tie, set of tools and complete machine log, is busily maintaining the machine, the visitor has the extra advantage of a demonstration or discussion of the machine's state. One of its demonstration programs of a mouse learning its way to cheese (or a martini) has been a favorite for 25 years-even though its graphics don't measure up to those on a handheld child's toy. For many, this seems to be involving enough, although not really "interactive."

To take the next step, to make the TX-0 operable by the visitor, is to put the clock back: the machine fills a room, yet is less powerful than many program- mable calculators, takes a half-hour to start and demands programming in its assembly language MACRO. This is an investment in time that most museum- goers don't make. But what about the rare person who feels that they must program the TX-0? For them, the machine is to be simulated on the Museum's VAX. Dan Klein from the Mellon Institute has put a number of the instruction sets for the classic machines, including the TX-0, on the VAX. The serious visi- tor can then have easy access to classic machines at a terminal in the new library of the Museum.

Another way to experience the TX-0 in action is truly vicarious: watching a 1961 made-for-television film about the machine, how it was used, with demon- strations of many of the programs. Such classic films will be used with many of the exhibits on super computers and vacuum tube machines that took in the order of 100,000 watts to turn on. Even if we got one of these machines together, the Museum could never afford to run it. Nor does it make any sense when the same computing power is available on a machine that requires a hundredth of the electrical power. To experience the size and power decline of the machines through the generations brings home the point better than any textbook statement.

Historic machines will only be one dimension of The Computer Museum when it moves to Boston. Several exhibition areas will emphasize contempo- rary computing with interactive exhibits that demystify the "black box." The first of these is "The Computer and the Image Gallery" now being planned by Oliver Strimpel, on leave from The Science Museum, London. The aim of the exhibition is to convey the full breadth of computer imaging, from computer- aided design to the simulation of galaxy evolution, from Landsat image-processing to computer-drawn animation.

In explaining the concepts of computer graphics, interactive displays will be used. What better way to understand how resolution affects a picture than to alter the resolution yourself? Or stretch the contrast, or distort the image with a simple mathematical function?

Computer graphics can also portray objects that do not exist in real life. Interaction allows the visitor to walk around them or zoom in on areas of inter- est. Simulations using computer graphics often rely on the choice of param- eters by the user, who gets more involved by entering his own choice.

The focus of The Computer Museum is not to create "interactive" exhibits, but to preserve and explain the scientific and technological history of comput- ing in the most appropriate and exciting way that it can be done.

Gwen Bell

The TX-0: Its Past and Present

Up and Running. For the third time in its history the TX-0 was fully operational, this time at The Computer Museum. It was built at Lincoln Laboratory in 1955 as an experimental computer to test transistors, and had its first birth in 1956. Then in 1958 it was dismantled and reborn at Massachusetts Institute of Technology (MIT) where it operated until the mid-sixties.

The TX-0 fills a room, yet has less memory than many personal computers. And unlike today's personal computers, the TX-0 demands a skilled user to maintain full-scale operation. The machine is a good example of what computing was really like 20 years ago.

Jack Dennis and John McKenzie were responsible for the TX-0 at MIT before its shutdown. This time around McKenzie was the operations manager and the first to witness it come back to life. He worked for months preparing the classic, 1955 computer for its debut at The Computer Museum.

His efforts paid off when TX-0 alumni, Museum members and other computer buffs united on Sunday November 13th, to display their enthusiasm for keeping the artifact in working, order. For one day, those who had be vital to the development and day-to day operations of the TX-0 reminisced about the days when it was at the apex of computer technology.

A series of events were held touch- ing on all phases of the TX-0's past. The day's events were videotaped for the Museum's archives. Included in the program was a lecture by TX-0 alumni and MIT Professor Jack Dennis on the history of the machine; a luncheon for the alumni; and a hands-on demonstration of the star attraction-the TX-0.

One alumni favorite was the mouse and maze program. Everyone focused on the mouse as he scurried across the cathode ray tube (CRT) screen to catch a piece of cheese. Old stories about the TX-0 abounded during the reunion with some alumni suggesting they should have brought cards for old times' sake, because bridge was often played during breaks in the TX-0 room.

The TX-0 at Lincoln Labs

The TX-0 and its original software were created at Lincoln Laboratory. Its original team included Wesley Clark as the logic designer and Ken Olsen as the engineer in charge of building the machine. Phil Peterson, Jack Gil- more, John Frankovich and Jim Forgie worked on logic design under Wes Clark. Bob Hudson and Chuck Norman were involved in the construction working for Ken Olsen in the engineer- ing group.

The following quotes are excerpts from discussions and presentations at the Museum's TX-0 alumni reunion held November 13th.

Jack Gilmore: The racks of logic that became the TX-0 were used to test both transistor circuitry and one-half of the 65K memory for the TX-2 computer that was on the drawing boards. Ironically, when everything was put together it turned out to be a fascinating general- purpose computer.

Phil Peterson: Imagine when the power was first turned on. We had no other machine to talk to the TX-0. In order to communicate with the ma- chine, the toggle switch panel allowed a sequence of bootstraps so that you could start a function, such as read-in the paper tape. The first thing we wrote was an octal assembler to read- in symbolic codes.

Architecturally, the machine intro- duced the idea of micro-coding. You could hit the carry pulse having never done anything else. A random num- ber generator that would make nice little patterns on the face of the CRT could be done with no instruction. Once the programmers got the idea of micro-programming they were only limited in their experiments by their imagination.

Jack Gilmore: Wes Clark wrote an as- sembler called Hark. It was arranged so that the symbolic addresses could be any length symbolic string, so we could incorporate English-language words, making programs easier to read. We put together one of the first on-line operating systems that could input software in a very easy fashion.

One of the most significant pieces of work was a brain-wave pattern rec- ognition program. Because the TX-0 had 65K of memory and an analog- digital I/O device, brain wave infor- mation was brought in as a moving window display. We were trying to teach the machine to recognize the "sleeping spindle." And because the TX-0 was the first machine with a coupled light pen and oscilloscope, the work was done four to five times faster than without these features.

Jim and Karma Forgie did voice recognition on the TX-0 before they did it on the TX-2. Because the program took 10-20 minutes to execute, Jim h -' the problem of finding .out where was. We rigged up a technique so he could draw a flow chart, put it on celluloid over the CRT, and in his soft- ware, slow down or speed up the pro- gram from the toggle switches. He could literally watch the voice pro- gram running through its steps. He could trap it and see it at a particular iteration using the Flexowriter or the toggle switches.

Most software was for testing the 65K memory. The complete cadre of software included a print program, Hark, the assembler, a technique for online assembling, a search program to search through memory and find things, a debugging routine, and the dynamic flow chart program. A fair amount of this initial software was not usable for the new 4K environment that the TX-0 had when it moved to MIT

The Move to MIT

In July 1958, the TX-0 was taken out -^f Lincoln Laboratories and installed . room 26- 248 at MIT John McKenzie recorded that it took 100 days of work to get the machine up and running.

The following is from a memorandum, dated July 23, 1958, to TX-0 users from Earle W Pughe, Jr.:

> This memo is written as an aide to those who wish to write programs for the computer before the computer is in operation.
>
> The TX-0 has 4096 words of magnetic core storage. The cycle time is six microseconds, thus each order normally will take twelve microseconds. The inputs consist of a direct typewriter and a photo-electric tape reader. The outputs are a typewriter, a paper tape punch and a display scope. Other inputs and outputs are the toggle switch register and indicator lights on the control console. Provision has been made for users to connect their own equipment to the computer.
>
> It is expected that in the future the TX-0 computer will have more orders and more memory. Every effort will be made not to obsolete existing programs as new features are added. However to help meet the objective of not obsoleting programs as the computer is modified, the unused bits of an instruction must be zeros. This restriction means that such tricks as shifting a word to change instructions will obsolete a program when changes are made to the computer. Bits "0" and "1" are now used for the instruction, bits "6" thru "17" are now used for the address and bits "2", "3", "4" and "5" must be zero for all orders except "operate."
>
> The Ad Hoc Committee on Experimental Computation (Chairman: Prof. J. E Reintjes) is the faculty group in charge of the computer and they have final decision as to who may use the computer. It is expected that with the cooperation of the users there will be a minimum of paper work in assigning computer time. Since the computer is to be used for experiments instead of for numerical computations, the blocks of assigned computer time will be considerably longer than

with other types of computers.

The Speech Research Group at MIT. Osamu Fujimura, Hiroya Fujisaka, John Heinz, Gordon Bell (with his hand over his mouth) and Professor Ken Stevens watch Pete Brady at the TX-0 console in 1959 at MIT

The TX-0 at MIT

Professor Jack Dennis: Because the TX-0 was created as a memory test computer, it had some peculiar characteristics. The size of the address for the TX-2 memory was 16 bits, while the TX-0 had an 18-bit word. How do you build a machine with a 16-bit address and an 18-bit word size? Since an ordinary single-address instruction format was used, only two bits were left for the operation code.

Wesley Clark was a major force behind both computers. When asked what happened to the TX-1, his response was, "We don't build odd computers." So the plans for the TX-1 were scrapped just like the DEC PDP-3.

Ben Gurly was responsible for engineering the display system for the TX-0, a unique piece of hardware that influenced his later design of the PDP-1 at DEC. The TX-0 was one of the earliest computers that allowed the operator to use the cathrode ray tube for interactive computation. In contrast, the displays on the Whirlwind were mostly used for recording information. The TX-0 display was used to show immediately the results of changes made to a program.

In the fall of 19581 had just finished my doctoral thesis and had been appointed instructor at MIT I also had just moved into an office in Building 26 near the TX-0. Not wishing to pursue further my doctoral investigations in operations research, I was open to new and interesting adventures. With a new computer down the hall, the hackery in my blood soon got me involved in its programs.

This computer, unlike MIT's number cruncher, the 7090, had the feature of being intimate with its users. You could actually go up to the console and ask the machine to execute instructions and programs specifically for you. The display program, which generated interesting patterns, triggered immediate reactions to fix it up and try it again. If one was careful in choosing the number in the "live" register of the machine, you could cause some wonderful patterns. You could do this with a program consisting of a single instruction-repeated endlessly. Such informal interaction with a computer was completely new to the world.

How do you build a sensible machine code with just two bits?

1. You must be able to store information into memory locations.

2. You must be able to get information out of the memory, so one can operate on it in the central processing unit. The TX-0 does not have an instruction code "load." In the TX-0, one got information into the accumulator by clearing the accumulator and then executing an "add" instruction.

3. The third instruction of the TX-0 was transfer negative: transfer control to the location specified by the address.

4. The operate instruction was next. Anything not done by the other three kinds of instructions was done by operate instructions. The remaining 16 bits instead of referring to a memory location were simply a micro-coded extension of the operation code. One combination would cause a point to be displayed on the cathrode ray tube (CRT) whose coordinates were the right half of the accumulator and the left half of the accumulator. In the same instruction you could transform the contents of the accumulator so that it would cause (on the next repetition of. instruction) a different point to be plotted on the CRT

Debugging

In the fifties a substance called FLIT was used regularly around the house to get rid of flies. Thomas Stockham and I called the debugging program we wrote for the TX-0, FLIT, which meant Flexowriter Interrogation Tape. It was a successer to UT3 written at Lincoln Laboratory and provided a medium for symbolic debugging. You could take the symbol table generated by the assembly program and load it into the debugger. The debugger could then talk to you about your program in terms of your symbolic addresses and symbolic instruction codes.

FLIT allowed one to insert breakpoints in a program and then run it. The debugger would take over control whenever a breakpoint was reached, whereupon the user could interrogate the state of a program and decide to go on or not.

The project to write FLIT was suggested by Professor Thomas Stockham who, perchance, shared my office in Building 26. We wanted FLIT to be a very interactive program, but we could not work with the cathrode ray display, perhaps because the character tables would take up too much memory. But more likely because many users would want to debug programs that used the display. Tom suggested that as soon as the typist had typed something that 1' was in error-something that would not make sense for any continuationthe program should tell the user about it. Tom invented an idea he called "hands lapping." Immediately upon typing an error, the program would type back a red question mark. This meant a lot of repairs to the Flexowriter because one would try to continue while it was typing back at you. Fullduplex communication and displays have now eliminated that problem.

About this time I heard of something called a "macro assembly" program and that Doug McIlroy had programmed one at Bell Labs. From this inspiration I wrote the program MACRO for the TX-0. This program was to lead to macro assemblers for the PDP-1 and other computers. MACRO turned out to be a large program. To debug it, it was necessary to use a simpler debugging tool than FLIT because FLIT took up too much memory, so I wrote a program called MicroFLIT FLIT and MicroFLIT were forerunners of debuggers written for other computers, including DDT (Digital ital Debugging Tape) written by Alex Kotok for the PDP-1.

Managing the TX-0

After the TX-0 had been at MIT for about a year and half, I took over responsibility for the machine and immediately set about extending the machine's instruction code. Since we were not likely to afford the 65,000 registers the TX-2 had, we enlarged the op code to four bits and added an index register. The operate command was redesigned to provide more capability, including logical "and" and "or"; and more input/output orders. With these changes the TX-0 lost its original power to generate fancy patterns through repeated executions of a single instruction.

Installing the new instruction set was a big undertaking. The machine was constantly in use by research staff and students. We made the changes by pulling one panel at a time during scheduled maintenance periods, and almost always had the machine back in operation on time. The correctness of the alterations had already been checked through simulation using a register transfer language to describe the new instruction set.

John McKenzie has managed every move the TX-0 has made, and managed operation and maintenance of the machine while it was at MIT He can tell you what it was like to replace the switches on the TX-0 console. I recall that when the machine first arrived at MIT, several switches had special designations: one was labelled "Suppress Wes;" and another was labelled "Dump Phil." These functions, doubtlessly referring to Wes Clark and Phil Peterson, are no longer present in the machine.

In my time one principle user of the machine was Gordon Bell who was working with Professor Ken Stevens and Arthur House on speech recognition. Pattern recognition was of great interest also.

Some of the people who worked on the TX- 0 became heads of the Information Processing Technology Office (IPTO) of the Advanced Research Projects Agency of the government, where MIT has obtained lots of money to carry out research. One of the directors of IPTO was Ivan Sutherland, who created the program "Sketchpad" on the TX-2. This benchmark graphics ` program allowed a user to create sketches on the display by using a light pen. Using the TX-0 light pen, Ivan and Claude Shannon wrote a program that would search a maze. It would act like it was inside a cave and would decide how to move by following the walls.

Larry Roberts, who also became director of IPTO, used the TX-0 for creating a kind of artificial intelligence program. His program recognized hand-drawn letters by learning from its experience.

In 1961, when John McCarthy was advocating timesharing as a way to use computers effectively and DEC donated a PDP-1 computer to the Electrical Engineering Department, my attention shifted to building a time-sharing system around the new machine.

TX-0 transistor. The first TX-0 transistors were in tubes to make it easier to test and replace them. The TX-0 had only 12 transistor failures, and almost every transistor that lasted more than 500 hours is still operational today.

Maintaining the TX-0

John McKenzie: When the TX-0 was built, transistors that operated at a five megahertz speed were not available. Lincoln Lab put Philco surfacebarrier transistors, costing $40 each, into bottles that contained 10 transistors. These were designed to be tested in a "transistor- checker." Ken Olsen, Ben Gurley and other designers didn't know whether transistors were here to stay. The engineers thought they might have to replace transistors like they replaced vacuum tubes, or at least annually check them. With little deterioration after 10,000 hours, it was clear that these transistors were good. It wasn't worthwhile testing them anymore. No one cared and the industry was moving ahead to new products. At MIT, only a dozen unaccountable failures may have been due to transistors. Most transistor failures occured within 500 hours after installation. Otherwise they made it, and are still working today.

Every time another feature was added to the machine, another power supply was added as a self-contained unit. The machine is cycled on in sequence and cycled off in sequence. You get the memory pulses before you turn on the read-write memory current.

John McKenzie. who spent months revitalizing the TX-0 for its Computer Museum debut, enjoys watching the machine perform on TX-0 alumni day.

Electronic Systems Lab Group

Doug Ross: John Ward had only observed the art of programming on the Whirlwind. When the TX-0 came, John decided he should program.

John Ward: I signed up and there I was in the room alone with the computer. I was terrified.

Doug Ross: Earlier at Egeland Air Force we built an elementary mouse solving a maze problem on the 1103. So John and I did a mouse and maze program. I did the logic and John the display.

John Ward: . . . very slowly. There was no assembler. You had to figure out all the addresses yourself. The style of the program was reminiscent of Shannon's mouse that used relays.

Doug Ross: It had more flexibility because we were able to use the light pen to place the mouse and either hide the three chunks of cheese or the three martinis.

For MIT's centennial in 1961, CBS did some specials on the Institute. The CBS director said, "Gee, Westerns are so cut and dried couldn't you write a program for one?" And I was talked into it. The memory was used to keep, track of everything down to the actors' hands. The logic choreographed the movement of each object, hands, guns, glasses, doors, etc. A line of English script was written for each direction, even if it went wrong. That's how we got the loop sequence which was an actual error run. If you watch closely, the sheriff puts his gun in the robber's holster, and other strange things.

Doug Ross. Seated at the TX-0's "L" shaped console, Ross explains how he and John Ward designed the Mouse and Maze program: "1 did the logic and John did the display."

Doug Ross explains the flowchart for the logical choices in "Saga," the 1961 TX-0- written Western.

Dit Morse: I've been asked if the error sequence was rigged. Well, it turns out that the CBS people were in the TX-0 room when the machine got into that loop. They saw what the programmer was doing and they grabbed that sucker so fast-they knew it was theater.

The program's 13,000 line code was macro generated. One of the first and only programs that I wrote with a real deadline. CBS would not postpone the shooting under any circumstances. It took six calendar weeks to deliver six skits.

Cognitive Information Processing Group (CIPG)

Don Troxel: As a graduate student I used the TX-0 because I had alot of numbers to reduce statistically, and . was the best desk calculator around. People in our group started to use it because of the display capability. At CIPG under the late Sam Mason we measured reading speed.

John Allen: The first speech synthesis by rules scheme introduced in England by Holmes, Mattingly and Scherm was first implemented on the TX-0. It made heavy use of this wonderful bank of switches to control the various parameters of that synthesis.

Don Troxel: When Francis Li called me over to hear it, I expected it to have a Chinese accent, but it had an English one since that was where the rules were made.

John Allen: We did experiments with pitch using the switches for control. The TX-0 and PDP-1 were used to start to build a reading machine for the blind. The character recognition part ran on the PDP-1 and the speech synthesis on the TX-0. The tenuous connection was often lashed together firmly enough so that we could read characters on the PDP-1 and have speech output on the TX-0.

When John McKenzie let you turn the machine on, you were then part of the in group. One Saturday, a professor, who will go nameless, called me on the phone and said, "I just turned the TX-0 on and it won't go."

I said, "Just put your hands on the console and don't do anything until I arrive." Fortunately he hadn't done anything disastrous. He just hadn't started up the clock sequence.

Gordon Bell: Actually with improper clocks when you started you could ruin the core memory.

John Allen: The price of the TX-0 was $3 million **-** from the development costs on the books at MIT

Gordon Bell: That was a bargain because it led directly to the TX-2 and Digital Equipment's first products.

> **Actor Jack Gilford** played the role of the robber in a "shoot out with the sheriff." The climax of "Saga" written in 1961 by the TX-0 with the help of programmers Dit Morse and Doug Ross.

Speech Research Laboratory of the Research Laboratory for Electronics

Gordon Bell: I was a member of the research staff of Professor Kenneth Stevens' speech research laboratory The laboratory continues to train researchers and do research in analysis and synthesis of speech. Some colleagues who worked on the TX-0 included Arthur House, now at the Institute for Defense Analysis; Osamu Fujimura of Bell Labs; Hiroya Fujisaki, University of Tokyo; John Heinz, John Hopkins; Morris Halle, MIT, and Pete Brady.

Speech was taken into the computer using a tape loop with sampling pulses on one tape channel. The audio (speech) signal was passed through a bank of 24 filters and read in via TX- 0's Epsco analog-to-digital converter. The goal was to recognize the speech by analyzing the frequencies of the resulting acoustic input. The analysis was carried out by a technique we invented called analysis-by-synthesis; the computer posted a model of the speech and compared it with that to be analyzed by adjusting the model's parameters.

Gathering vignettes. Steve Levey (left) who is writing a book on hackers, gathers tidbits from recollections of Electronic Systems Lab Group alumni Doug Ross (center) and Harrison (Dit) Morse.

Reminiscing. Shag Graetz's first hands-on programming experience was at the TX-0 console, although he was a seasoned programmer before coming to MIT.

The Hackers

Alan Kotok: In the fall of 1958, I was one of the earliest of the undergraduate crew to come in. Jack gave a couple of introductory talks to the Tech model railroad crowd, and brought us over to demonstrate the TX-0. When we saw it, we said, "Oh, neat-there's all this time available." We negotiated with Earle Pughe and John McKenzie for time. They said if the faculty advisor was amenable, then we could use the machine without any supervision.

Jack Dennis: As an undergraduate I wrote a large linear program on the Whirlwind to solve the transportation problem. After midnight, I could get my hands directly on the Whirlwind, and get scope postmortems all on my own. This led me to believe that informal direct programming by students was the way to work with machines. Then we formalized it on the TX-0.

Dave Gross: I was a freshman at MIT in 1957 and got a tour of the new TX-0 computer room. In 1958 we, the model railroaders, discovered the TX-0. I was told that under no circumstances could I turn it on, since I was not an authorized user. The most elaborate program I wrote for the machine was a three by three matrix of dots that made a search. One night Alan Kotok and I had the idea that it would be awfully nice if you didn't have to run your program tape through the reader twice. So we wrote a program that put it on mag tape the first time with enough space for binary to be added.

Alan Kotok: Before that no one had used the tape except to write from the beginning and fill it full. Here we wrote-and then left space along the way.

Dave Gross: We tuned it to leave just the right amount of space.

Alan Kotok: We put two load points on all tapes, with the utility at the beginning and then a point that allowed use at the end. We did anything to avoid having to punch another binary program on this Flexowriter that punches ten characters per second.

Dave Gross: Alan, do you remember the expensive tape recorder program? You had your FM receiver here in the computer room and we said we'd hook up the audio to the A to D converter and write a program to record on that tape. Alan Kotok: That was digital recording more than 20 years ahead of its time.

Dave Gross: It would write the whole tape as one long record. Play back through the accummulator created a whistle, so we used the scope's D/A converter fed back into the speaker that was under the console.

Jack Dennis: Could you recognize Beethoven?

Alan Kotok and Dave Gross: It wasn't bad, considering . . .

Alan Kotok: After the PDP-1 arrived and before any of the fancy high speed links had been installed between the machines, the hackers of the day and I were contemplating how we could make use of both computers. We hooked up a serial line between the two with a buffered program to the typewriter. You could type a line at one machine and it would come out on the other.

After we got it working, I said, "What can we do with this?"

Someone said, "Play chess."

Since some of us had been working on chess on the 7090, we got together a panel of chess players in the TX-0 room with a chess board. Some of us sat in the PDP-1 room with a chess board and waited for an unsuspecting chess player to walk down the hall and into the room. Some fairly gullible graduate student was enticed to play this great new PDP-1 chess program. Our victim typed his plays in. The group in the other room replied. It worked well for a while, but then there was confusion about one of the moves with an argument over the terminal. Alas, our victim smelled a rat and started for the door to the connecting TX-0 room.

Gordon Bell: In the spring of 1960, 1 went out to DEC and bought some modules so that we could add a mag tape unit on the machine.

Alan Kotok: And that took us into big time computing.

Jack Dennis: I remember that my dream at the time was getting support for interactive programming on the TX-0, even though the one itty-bitty tape unit was the only bit of auxiliary storage we had. I was dreaming up schemes to keep peoples' files and images on this tape unit, so that one user could take the machine over from another, but that project was scuttled when the PDP-1 arrived in 1961. Then we started to use it to build a timesharing system.

Shag Graetz: By 1961 this machine was a legend among programmers. I had been eased out of the nest at Harvard where I used the 704, with about three times this amount of equipment, that no ordinary programmer could ever use. I came to write a diagnostic program for the 906/2 tape drive-every bit the kludge that it appears to be.

My first question was, "Who is the operator and how do I submit my programs?" Jack Dennis said, "This is it. What you see is what you get." The entire room of machinery was under the control of whoever was signed up to use it at the time. During the next academic year, I went to work for Doug Ross; the PDP-1 arrived and I moved over to work on it, where in our spare time we developed SPACEWAR!

Deja vu. John McKenzie who was the technician on the TX-0 at MIT, once again readies the machine, but this time at The Computer Museum.

The Move to the Museum

John McKenzie: The TX-0's life came to an end when each of the labs got their very own computers. When I saw a note in the paper that Bob Everett was presenting the Whirlwind to the Smith- sonian, then I thought that's the place for the TX-0. However, they weren't interested. A little bit later, I saw a short paragraph in a DECUS newslet- ter that DEC was starting a museum. And we said that was the way to go. Stan Schultz came down and we started to plan the move. We were about to move the machine on April 19th (a holiday), when the contract officer at MIT said, "Hey you can't give away this $3 million to a private individual." Everything came to a halt for two years. First it had to be offered to all military groups, then to all groups with government contracts, then vari- ous universities, then secondary schools, and finally to general ser- vices who could advertise it. On the first go-around DEC was outbid $2500 by an outfit in St. Louis that wanted the I/O. Then it was re-advertised. This time DEC was outbid $50 by a surplus dealer in Ohio. Roy Gould got busy on the phone and noted that it would cost a lot more than the price of $350 to move the machine. DEC gave them an extra $100 and took title to the machine.

Stan Schultz: John Connally and I spent many hours labelling all the wires.

John McKenzie: The dismantling took about a week, and then unfortunately it went into a warehouse for about two years.

Stan Schultz: Initially we set up the processor and console, and it was on exhibit from the summer of 1979 until 1981.

John Mckenzie: We never burned any bridges so that we could make it run again. Fifteen different power supplies were lost in the warehouse. Then we had to buy some new ones. But the CPU is pure. Twice in bringing up the machine I was stymied. Once with the core memory, and I called on Dick Best to do some circuit analysis and he got me out of that hole. Later on, in setting up the paper tape reader, Alan Kotok did some analysis and we made it work. It needs to be in a computer room environment with a cooler, steady temperature.

Stan Schultz: While on exhibit, some people must have taken souvenir bottles from the console. When we let it be known that the machine was being brought up again, bottles would mysteriously appear on the console.

Otis King's Pocket Calculator

is a rare pocket-sized cylindrical slide rule manufactured by Carbic, Ltd. in London in the early 1920's. The spiral logarithmic scale, printed on both the smaller rotating and larger fixed tubes (called "cylin- der" and "holder") is a double scale with five places of accuracy. The cylinders can be moved relative to each other either axially or rotationally. Two arrows at either end of the sliding black cover form the tubular cursor (that mark the logarithmic numbers and their roots).

Otis King's Pocket Calculator, gift of Harvard University Professor I. Bernard Cohen, was moved to Boston with the Calculator Collection in February and will be on permanent display in the Pre-Computing exhibit.

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Highlights from

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Computer Engineering Attitudes From Eckert-Mauchly to Analogic

Bernard Gordon

In 1948 Bernard Gordon graduated with a bachelor's and master's degree in electrical engineering from Massachusetts Institute of Technology (MIT). After starting with Philco Corporation, he joined the Eckert- Mauchly Computer Corporation. Today he is the president and technical director of Analogic Corporation which is engaged in the development and manufacture of high-precision, high-speed signal translation and information processing equipment. The following abbreviated and edited excerpts have been derived from a lecture presented by him at The Computer Museum on October 20, 1983. For historical purposes, the original presentation has been archived at the Museum on videotape.

About a year after I left MIT to start work at Philco Corporation, I received a call from Presper Eckert who told me I had been recommended by a professor at MIT and asked if I would come over for a job interview. Eckert, then about 28 years old, gave me such an intense technical and personal interview that even before he made me a job offer I told him I'd take the job just because he had motivated me to show him what I could do. He was so taken aback by this that, I guess, he felt he had to hire me and so he did.

Therefore, in 1948 on a hot summer day I reported to work at the Eckert-Mauchly Computer Corporation in Philadelphia in an old building near Wissahickon Park. One of my first memories is that of seeing A1 Auerbach, now a long-time friend, standing literally in his underwear working in the middle of the heat of the circuitry which was supposed to become the BINAC, forerunner of the UNIVAC. As I recall most of the small group of engineers were nearly all in their twenties. The chief engineer was Jim Weiner who had come down from Raytheon. Jim ruled over us like a master sergeant and engendered in us reactionary passions . . . but he made us do our jobs. In later years I learned to bless him because he and Eckert inculcated in me, and I believe in the others who worked at the Eckert-Mauchly Computer Corporation, engineering disciplines which have served me well during the past 35 years.

It is interesting to note that EckertMauchly had figured out that they would need about $100,000 to engineer the UNIVAC and ready it for production. They had raised about this amount of money from the American Totalizator and had figured out this amount of money based literally on the number of solder joints in the machine and multiplying that by so many pennies. They therefore had predetermined the rate at which all of the work must be accomplished from logical design, the software, the electronic design, the construction, and the debugging.

Eight to ten engineers were to build, not knowing any better, all of the original circuitry for the UNIVAC and as well the first high-speed startstop digital tape mechanisms, the tape plating and manufacturing facilities for those tapes, the first-known card-to-tape converters, and the many other major sub-units of the UNIVAC system.

The machine was to have approximately 5,700 vacuum tubes, used primarily for amplification and pulse forming and 18,000 semiconductor diodes used primarily for high-speed gating. (It may be interesting to recall the semiconductor diodes utilized were purchased as war surplus materials from Western Electric.) When I arrived for work one of the engineers, Bob Shaw, had already essentially single-handedly drawn all of the detailed logic diagrams. I recall Eckert saying to me: "You are going to design the circuits, standard flip flops, standard gates, and so forth." He had allowed only a few working days to do this. I didn't know I couldn't do it, so I set out to do it. In a relatively short time, no more than a few weeks, we had designed and proven the capabilities of the standard gates; I then designed the I/O circuitry, supervisory control circuitry and tape control circuitry, standard flip flops and what we'd call pulse formers.

Eckert then set me to work to design the crystal transducer system for the acoustic memories of the UNIVAC and then all of the electronics for the memory system. The time allowed for each major design was always measured in days, not weeks or months. At that time I thought I was working on the world's first acoustic memories and it wasn't until a considerable time later that I found out that Maurice Wilkes, who is present at this lecture, had actually built a unit earlier in England. While I was carrying out this work together with the other engineers at the Eckert-Mauchly Computer Corporation, Pres Eckert and Jim Weiner taught me via their direction a number of factors about engineering and engineering supervision. I do recall that at the time we were receiving this type of direction we felt that they were very tough. But in the process of being apprentices to these master engineers, most of us went through a maturing and learning process which, in retrospect, I wouldn't have traded for anything. If in my later years I have myself developed a reputation for being a tough engineering task master, I am pleased to say-and I hope that he will be pleased by my saying it-that Eckert was responsible.

For example, after Eckert more or less gave me a "gold star" for doing the acoustic memory, he put me in charge of a few other even younger engineers who were then being hired into the company. He gave me the following directive: "If you ever see an engineer studying during work hours, I want you to give him his first warning. If he does it a second time, terminate him." His view was, and it still remains mine today, that people owe it to themselves to further their career, to study at home, and that they should come to work prepared to get the physical work done.

The philosophy of "worst case design" probably originated, or at least was formalized, at the Eckert-Mauchly Computer Corporation. Eckert and Weiner insisted that when we design something, we must design it thoroughly, into the ground so to speak, and release our circuitry to production without ever breadboarding. In the first UNIVAC they established rules for derating such that every 25L6 vacuum tube must properly function in its circuitry with its emission dropping to approximately 50 percent with the screen voltage varying, with the heater voltages varying, with carbon resistors changing 20 percent, etc.

Although I didn't really prepare for this lecture in any formal way, as I stand here, I can remember the derating numbers of 35 years ago like a catechism. For example, every germanium diode which had a nominal back resistance of about a megohm with a back voltage of 30 volts had to continue to work satisfactorily if that back resistance went to 18,000 ohms. Every carbon resistor had to be able to change 20 percent and each power supply voltage had to change in the worst possible combination, about five percent. As a result, we were able to design with parts that really weren't very good and design equipment that could be predicted to work right essentially the first shot.

Eckert taught me to pay great attention to every detail. He taught me that the design engineer was responsible for every aspect of the design. The engineer should know how the components were made. What were their strengths and what were their weaknesses. There should be extreme tolerances on everything. He knew that only by doing this was it possible to make a machine with 5,700 vacuum tubes each with a nominal emission life of about 5,000 hours work at all. However, by applying the rules of derating everything, it was possible to make a machine at that time which worked for acceptable periods of time.

At the end of every week, Eckert and Weiner would come around and we'd show them our big schematics with 40 to 100 vacuum tubes on them. He would look at a drawing, almost closing his eyes, and point to a resistor at random and say: "Why is that resistor that value? Why isn't it five percent higher? Why isn't it five percent lower? Show me in your notebook where you proved absolutely that that resistor is exactly the right value." I think I almost got fired one day because I had a grid resistor returned to ground, and he asked me why. I said that it was half way between plus and minus infinity, which was an unsatisfactory answer.

Every once in a while something humorous related to the disciplines that were put in effect would take place. For example, whenever the power came on the UNIVAC, a red light went on at the top of the machine's frame. Jim Weiner established the rule that whenever anybody made a mistake such as putting a screw driver or a scope probe in the wrong place and blew up a diode, he would have to buy a Coca-Cola for all the employees of the company, approximately 30. However, one day Jim Weiner himself put his screw driver into the wrong place and blew up all 18,000 diodes! It made us all feel much better. No one ever found out how he was able to blow them all up simultaneously, but he sure did.

I have always felt that Eckert conveyed a particularly important engineering philosophy to us. He felt, I believe, that any engineer worth his salt should be able to design anything at any time, either electrical or mechanical. If he didn't know how to do it, then it was his responsibility to go out and learn how to do it. I remember his saying to me: "When you go home tonight, your wife is going to want you to cut the grass. Don't do it. Hire somebody else to cut the grass who is a grass cutter, and you study and design for the company." He said: "This effort will come back to you many times in the future." I nearer did cut the grass and always felt as a result of his direction that it was my mother-in- law's job to take out the garbage and not mine! In any event, I have always spent continuously over the last 35 years two hours a day studying at home or at the MIT library or elsewhere . . . every day.

Al Auerbach and Jim Weiner (right), who according to Bernard Gordon, "established the rule that whenever anybody made a mistake such as putting a screwdriver or a scope probe in the wrong place and blew up a diode, he would have to buy a Coca-Cola for all of the company, approximately 30."

J. Presper Eckert Jr. is shown with a BINAC Mercury Memory Tank. To engender his attitude, every once in a while Eckert would notify all the engineers that they would be given a written test. The test material generally had nothing to do with our then

went work. The test material would touch upon a variety of subjects, such as the workings of an alternator or a power station or how to design a filter. If an engineer could not pass such a test, he was likely to be terminated. This, I believe, was Eckert's way of making sure that his engineers had a very broad interest and would be prepared intellectually to tackle anything that they had to. It was not unusual that one engineer such as myself would design wide band IF amplifiers one week and stainless steel tanks with crystal transducers for sonic mercury systems another week.

Eckert, through his personality and the fact that we were building the first commercial computer, got us very excited and interested in our work. Not only the theoretical and technical aspects but also the economic aspects. He used to get us to think in terms of how much everything cost, how much did the solder joint cost, how much did it cost to make a drawing, how much did it cost to have a secretary prepare a technical document, how many lines sould a draftsman put on a piece of paper each day, etc.

To try to keep within his original $100,000 budget, it was required at the Eckert- Mauchly Computer Corporation that every day one vacuum tube's worth of circuitry be released into production about every half hour by every engineer. There was no getting around it. Those were the standards set and that is what was expected. As I recall it was less than a year after the design started that the UNIVAC fully stood on the floor at the Eckert-Mauchly Computer Corporation complete with the first high-speed start- stop tape mechanisms, first acoustic memories, tapeto-card converters, ready to be system tested.

We probably didn't know it at that time, but nearly all of the engineers at the Eckert-Mauchly Computer Corporation were highly motivated by the atmosphere which I have briefly described. About the time of the completion of the UNIVAC 1, the then Sperry Rand Corporation bought out the company and the culture began to change "big time management" attitudes began to permeate the company. Many of the original engineers, including myself, then began to leave the company. Eckert, who had been my mentor, said to me when I left: "You may never build another computer again, but it is probably true that everything you build in the future will in one way or another resemble a computer." He was right.

After Eckert-Mauchly

Eckert's prediction was proved on my next job. I moved back to Boston because the weather was too hot and muggy in Philadelphia. In Boston I worked for a company called Laboratory for Electronics, founded and populated with very famous names from MIT's radiation laboratory and who indeed had made major contributions to the series of well-known books entitled RADIATION LABORATORY SERIES. The company wanted to build a computer. But since the guys from MIT wanted the job, they were given the opportunity. I was assigned to work on the development of a doppler navigating radar. One day we realized that every half cycle of the doppler return signal represented the distance that the plane had traveled. So we thought that if we could count these half cycles, in turn we could build a digital doppler radar. Thus, consistent with Eckert's prediction, the doppler radar which would normally have been an all analog system ended up resembling a digital computer.

It was also on this job that I met An Wang who had just started his own company. He and I built a sequenced number generator which resulted in patents for wire core memories. We pulsed stacks of magnetic cores in sequence and read them out to generate arbitrary codes for controlling our rate multiplying navigational computer.

In 1953 I decided that it would be useful to tie computers together with analog signals and built a device called a DATRAC, the first known shift programmed successive approximation A/D converter. At that time together with another gentleman named Joe Davis, I started a company called EPSCO, Inc. and began hooking up analog to digital converters to computers . . . an activity I have been heavily involved in ever since. Today at Analogic we build a variety of measurement devices that compute, varying from very sophisticated phased- array ultrasound medical imaging machines to high-speed signal processing computers.

I have consciously and unconsciously tried to follow some of the principles that I orginally learned in my younger days when I worked at the Eckert-Mauchly Computer Corporation. At Analogic we expect that project engineers should personally be able to do the variety of tasks required on their projects. We rarely put more than three or four engineers on even the most complicated equipment that we design, such as the very first instant imaging CAT scanner or signal processing communications computers that make hundreds of millions of computations a second. Our project engineers who can be assigned from project type to project type are the keystones of our company.

Very often people from all around the world ask us: what do we at Analogic do that is different to get the engineering productivity and stability of our engineering staff. I always answer by saying: "We don't do anything different. You are doing things different. We are doing the same old things that we learned 30 or more years ago."

Let's briefly look at how things used to be and how they are today. In 1948 there were about 2,000 electronic engineers being graduated in the United States. Today with 250,000 electronic engineers nominally at work in our society and about 17,000 graduating each year, a hue and cry is heard across the nation that there is a shortage of engineers. What is wrong? In the 40's, engineers were taught, in addition to the type of disciplines that I have referred to, a breadth of mathematics and physics. They could be prepared to do anything because they'd been taught fundamental principles.

Recently I attended a seminar where a speaker stated that "the complexity of current projects is such that the mind of a single project engineer cannot encompass the breadth of the work." That fellow was talking about an engineering work station. Another fellow made a similar point about personal computers. Those of you who are in the audience who are about my age know that this is nonsense, because we were all called upon, when we were younger, to build and be totally responsible for much more complicated things. Certainly there is not a heck of a lot of real physical hardware engineering in any personal computer. Any good engineer could design a personal computer hardware-wise in a few weeks. The software would clearly take longer. But for the hardware, he needs to have an organizational concept utilizing available chips or have them laid out in gate arrays, buy a display and storage elements, and essentially "glue" it together. It would probably take longer to get the tooling for the plastic case than to actually design the personal computer. Bear in mind that with

Eckert's $100,000 engineering goal (even if that translates to $500,000 today) he intended to design from scratch the world's first commercial computer, the world's first card-to-tape converter, the world's first commercial acoustic memories, etc. Keep in mind that there was typically a half to one engineer working on each subsystem.

Now, let's look forward a couple or so years when you will probably be able to hold in the palm of your hand a 10 megaflop 32-bit high-speed computer with about a million bits of memory whose factory cost will be $200 or $300. When such building blocks are available, much of the "beauty" of this fellow's computer architecture or that fellow's computer architecture will fall by the wayside. The tasks for computer-related systems will be more and more related to being able to harness that computing power and design and build useful real-world machines encompassing a breadth of technology

Now, what has happened to engineers? I would like to state my opinions and I am aware that not everyone will agree. In most companies the attitudes of Pres Eckert or Jim Weiner are no longer taught nor is the mentor relationship available to most young engineers. It is very rare for a youngster out of school to go to work for a 28 year old truly experienced engineer. He is liable to go to work for another youngster who has only been out of school for two years, who in turn has worked for a youngster with a similar limited level of experience.

I believe that with about five percent supervision by a broadly experienced motivating engineer, less experienced engineers can increase their productivity somewhere between two and three times. At Analogic we jokingly call this "Gordon's Rule" and are certain that the theoretical parameter of improvement is "e" or 2.7183.

Now, some people such as the people developing work stations claim that by the appropriate use of engineering work stations it should be possible to increase engineering productivity by 4 to 1. Possibly they are right and possibly Gordon's Rule is right. Of course, if they are both right, then it must be possible to achieve a ten-fold increase in engineering productivity. If this is so, you would think that this combination would easily solve the engineering shortage!

However, in my opinion the reality is that the true problem is that there is a grave shortage of engineers whose education and orientation gives them a very broad view. Recently I became concerned about the breadth of capability of many software engineers. The following may be instructive. When Eckert interviewed me in 1948, I had learned a great deal about "pole and zero- based transfer functions" by working at Philco. When I had to design an IF amplifier for the UNIVAC, I was able to achieve an overall transfer function by matching the effective poles of the transducers to an optimum complementary transfer function of the amplifier. Recently I started playing with my little home computer and just to exercise myself decided to write a program for an arbitrary number of poles and zeros to calculate the phase and amplitude transfer functions and the transient response. Having once known how to do this very well mathematically and particularly knowing the graphical interpretation of pole zero relationships, it took me only a few hours to achieve the result I desired. The next morning upon arrival at Analogic I asked one of our relatively new but previously experienced software engineers how long it would take him. His answer was six months! At first I was startled, but as I proceeded to talk to him, I discovered that he could probably write the program in two hours also . . . if he knew something about poles and zero mathematics . . . but that he felt it would take him five months 29 days and six hours to learn about poles and zeros! Then he could write the program.

We can all recount examples of projects where hardware engineers, software engineers, marketing people or customers could not interact effectively because they did not understand each other's needs. It is my belief that in the 36 years since I went to work for Eckert, I have witnessed a continual decline in the average productivity of engineers. Let's take a measure of it. Only 25 years ago it was common to say that there should be a development engineer for every million dollars worth of electronic production in the United States. Now, 25 years later, with an inflation factor of at least four and with the availability of CAD/CAM techniques, LSI and VLSI and all the other modern wonders, a computation of the total electronic output in the United States divided by the number of electronic engineers at work yields a value of only about a half a million dollars. This combined factor of eight is of great economic significance. It should cause most business managers and technical leaders to pause and give consideration to whether they have allowed the standards of engineering excellence and productivity to decline in their own organizations.

Question and Answer Period

Q: Did Eckert ever really fire someone for failing one of his tests?

A: Yes.

Q: How could you keep working if you thought your job was on the line?

A: I'm not suggesting that somebody should be fired because they don't know something, but if they won't learn something, that is different. Not too long ago I fired a mechanical engineer who would not draw. He said that he thought up designs "in his head" and he would then translate his thoughts to a draftsman . . . and that it was beneath his dignity to draw. We found that he really couldn't draw and didn't want to learn. He had a degree in mechanical engineering . . . but had never taken a drafting course!! He's not atypical.

Q: What was the role of John Mauchly? A: I believe that Mauchly was the original driving force behind the ENIAC. He was a professor at the University of Pennsylvania, and Eckert was a graduate student. They founded the Eckert-Mauchly Computer Corporation. At the time I was employed, Mauchly was somewhat less active for reasons, as I recall, that were very personal.

Q: Was there a strict hierarchy and structure?

A: Although Jim Weiner was the chief engineer, Eckert would often jump up to the top of a filing cabinet and sit on it and squat. He would take on the characteristics of a guru to anyone that was around at the time. As I recall there really wasn't a pecking order at all. He used to have what I thought was a wonderful idea of saying to people, "Say anything that comes to your mind. Idea. Idea. Idea. You have 99 inadequate ideas and maybe the 100th will be invaluable." Eckert would always engender an atmosphere where people would not be afraid to be wrong about anything. We all had a lot to learn and to conceive.

Note: Recently the Massachusetts Board of Regents has authorized the formation of a new institute to be called The Gordon Institute, a school of engineering leadership to be located in Wakefield, Massachusetts. Its aim will be, consistent with Eckert's philosophy, to teach engineers a breadth of knowledge involving technology, ethics, and philosophy, considered to be musts for true leaders and to develop an orientation toward the successful economic accomplishment of projects undertaken.

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IBM System/360

Bob O. Evans

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The System/360 and its direct descendants have accounted for more than a hundred billion dollars worth of revenue and considerable profit for IBM and has been the foundation of our basic business for years longer than we anticipated. I wish to tell you something of the environment, actions and people who made System/360 happen.

IBM was formed in 1911. At that time it was called the Computing, Tabulating and Recording Company and was an amalgamation of three tiny companies that worked on products such as meat slicers, scales and nurse call systems. One part of the small firm was the Tabulating Machine Company that had been built upon the intellect of Herman Hollerith, inventor of the punched card. This little company, recording a few tens of thousands of dollars of revenue, grew slowly in those days. By the early 1930's, CTR had grown and, amazingly, had shed itself of most of the prior products, the nurse call system, the scoreboards and the meat slicers, concentrating upon the Hollerith concept to become an electric accounting machine company.

Several factors accounted for CTR's success: first, the strength of the Hollerith concept itself; second, the young leader who ran the company Thomas J. Watson, who had come from the National Cash Register Company; and, third, the U. S. Social Security Act of 1931, which created an enormous demand for the types of machines CTR built.

The Computing, Tabulating and Recording Company's name was changed to International Business Machines in 1924. In 1930 IBM's revenue was $19 million a year and then grew by 1939 to $38 million a year. A more important measure of the effectiveness of the company is net earnings after tax-which were 36.8 percent in 1930. Of course the tax structure in those days was substantially different. Nonetheless in net: IBM was a healthy small company, producing electric accounting machines for a growing demand.

By 1949 IBM had grown to be a $200 million a year business that primarily leased electric accounting machines. The view within was that IBM was the product leader in electric accounting machines; it was a profitable institution and investors loved IBM. If you had bought a few dollar's worth of stock then, you would not have to work now. IBM had very strong user loyalty, and most importantly, there were abundant opportunities for new electric accounting machines.

Let us examine IBM in the decade of the 40's in more detail. There was a revenue bulge that came during the war years as the company-like all U. S. industries-turned to the national effort. Then there was some downturn as the company recaught its breath after the war to return to its basic business direction. Profit was 20 percent of earnings in 1939 and by 1949 profit had grown to $33 million or 18 percent net after tax.

In the national interest work during the war years IBM produced fire control systems and navigation and bombing systems among other products. From this IBM's Military Products Division grew, and was later renamed the Federal Systems Division, although the revenue of that division is today a small percentage of IBM's total.

New events led IBM to turn another radical corner. One often wonders how these things happen and, on reflection, the change was most unusual, for here was IBM doing well with electric accounting machines when the Korean war started. Shortly after the war broke out, Mr. Watson sent a telegram to President Truman offering IBM resources for the national effort. The consequence of this telegram was that two IBM executives surveyed the National Laboratories and other national interest work around the United States to determine what IBM might do. One was an engineer named Ralph Palmer, in my viewpoint one of the geniuses that IBM was fortunate to attract, who established the foundation of the IBM development community as it still exists today. The other was a master salesman, Dr. Cuthbert Hurd. Dr. Hurd and Mr. Palmer, under the aegis of the Watson telegram to the President, toured the U.S. They visited such places as Livermore, Los Alamos, National Security Agency and aerospace companies to determine how IBM might contribute. When they returned they told Mr. Watson the best thing IBM could do was build a high-speed computer much like the high-speed com puter that Dr. John von Neumann was building at the Institute for Advanced Study and Professor Maurice Wilkes was building at Cambridge University. They concluded there was great need for such computer power in national interest areas and that IBM should do it.

The government was not all that interested, so Mr. Watson, anxious to keep his pledge, decided that IBM would fund the effort, thus in 1950, the project began.

A principal viewpoint then in IBM was that such a project was an intrusion on the mainstream. The estimated demand for such electronic systems was ten or so and the prices were certain to be astronomical. Thus the view was the project was indeed a sacrifice, but IBM should get on with it and then get back to our basic EAM (electronic accounting machines) business as swiftly as possible.

The project was called the Defense Calculator and was formally named the IBM 701 Electronic Data Processing Machine. The first system was installed at IBM's World Headquarters in New York City in December 1952.1 was lucky to be one of the engineers who went to New York City to get that system installed and operating. Nineteen 701's were built betwen 1952 and 1954. The rental for the system was a staggering $20 thousand a month at a time when other IBM machines rented for $300 a month or so. Thus, the 701 did not seem to have much promise. Fortunately Mr. Watson's son, Tom Watson, Jr., saw the potential of electronics. He had become President of the company and pressed for more effort in electronic computers. You can imagine the reaction of some senior management. They knew the accounting machine business, they loved it and there were long lists of new EAM features and equipment needed to meet customer requirements. Thus many pressed to continue focusing on EAM. But Tom Watson, Jr. led the business into electronics.

In the 1952 and 1956 era of vacuum tube technology, a number of computers came from IBM. The business computers were characterized by being alphanumeric, handling both alphabet and numbers, and operating serially by character on those voluminous strings of variable character length data. Business systems also had more extensive peripherals, usually tape drives, card machines and printers. In contrast to the business systems were scientific systems such as the IBM 701, which were parallel, binary and had more limited peripherals.

IBM 701 Electronic Data Processing Machine, 1952.

IBM 704,1955.

IBM Growth: 1930-1939.

IBM Growth: 1940-1949.

In a short time an improved version of the 701 was produced called the IBM 704. Gene Amdahl had come to IBM from the University of Wisconsin, where, as his doctoral thesis he built a machine called the WISC. He, John Griffith, and a small group worked on the architecture of what became the 704 with new innovations such as floating point, indexing, and other bright new functions. Later core memory replaced the old Williams tube memories and, still later, the IBM 709 evolved from the 704 base. In that era another business computer was produced, the IBM 650, centering about a magnetic drum storage device. More than a thousand 650 computers were sold, far more than the forecast.

The 305 RAMAC was a new system conceived by Ralph Palmer, IBM's engineering genius. He wanted to see business data immediately accessible to the processors and he envisioned a disk device. Palmer set up a laboratory IBM's third, in San Jose, California, to develop disk products. The 305 RAMAC became the first disk system that IBM produced. The sales forecast was for four or five thousand although fewer were sold.

Also on the business systems side, several hundred 702 and 705 systems mere produced. They rented for more than $30,000 a month, taking the place of a lot of sorters, collators, gang punches and calculators that were then the mainstream of IBM's business. Some 250 704's and 709's were sold to scientific users.

These big rental, big ticket items brought in a lot of revenue to IBM in that exciting period. So Tom Watson, Jr.'s hunch about electronics proved correct and IBM was on its way into a new era.

How did the business do? Through the decade of the 30's and the 40's the company grew to $200 million. Now we see the consequences of the shift to electronics for, in the decade of the 50's, IBM grew swiftly to approximately a billion dollars in 1957, and in the following two years to $1.6 billion, fueled by our movement into electronics.

IBM Growth: 1950-1959.

IBM Vacuum Tube Computer Families: 1952-1956.

Some companies working on the early computers were ahead of IBM, and I would have to say that IBM was able to succeed so well because of our marvelous sales force and outstanding service which were the keys to IBM's ability to grow from a small company to the very significant company we became in the 1950's.

Profit margin for that period was somewhat reduced as heavy investments were going into electronics. After tax margin declined to 10.9 percent, still healthy by most measures.

Then we entered the transistor age. IBM announced its first semiconductor system in 1957 and delivered it in 1958. Through the period of 1959 and 1960, IBM brought out a number of systems, some with new architectures and some with evolved architectures based on their vacuum tube predecessors.

For example, the 7080 was a semiconductor version of the 702 and 705 business systems. It was brought out because the new architecture 7070 business system had not done as well as had been expected. Customers that had 702's and 705's were not converting their programs to the radically different architecture of the 7070, thus the compatible 7080 was produced. Less than 100 of the 7080's were produced, yet the system was a business success.

A special story, however, was the 7070 which was IBM's new business architecture entry for the semiconductor age. RCA had produced their vacuum tube BISMAC series and then moved to their transistorized 501 series. The 501 had good performance and price, and IBM was racing to compete before we lost initiative in the business systems area as business applications were viewed as being 80 or 85 percent of the demand in those days while scientific applications provided the rest. Thus the 7070 was a new era system that we hoped would retain IBM's position and .allow us to grow from that base.

Ralph Palmer had done something that was typical of him: he held a competition to determine which laboratory was going to design the

7070. Poughkeepsie, IBM's large systems laboratory, had a design that was attractive and they vied for the responsibility of building IBM's new transistorized business entry, essentially the plum of the development community.

The Endicott laboratory, which had earlier produced the 650 system, had its own version of what to do: they proposed to build upon the 650 architecture and Endicott worked hard to win the prize. When the dust settled, Endicott had won the mission with a lot of aggressiveness in proposing features and function in what was to become the 7070. It turned out, however, the 7070 was such a complex system that it did not sell as well as had been expected.

Dawning of Transistor Age for IBM Computers: 1957-1960.

In the meantime, in Endicott there was work on replacing electric accounting machines with stored program computers. IBM had been struggling for seven years to find a way to consolidate in an electronic system the capabilities that were found in the assorted unit record machines such as gang punches, collators, sorters and calculators. Several approaches had failed because the people working on the designs had tried to build systems with plug boards which were the control unit in the electric accounting machines.

A bright engineer in the Endicott laboratory, Fran Underwood, conceived a von Neumann stored program system that became the IBM 1401. That system, announced in 1957 and shipped first in 1958, went on to become, from IBM's standpoint, the Model T of the computer industry. It rented at $2495, an unprecedented bargain in contrast to the $20, $30, $40 and $50 thousand per month that customers were paying to rent the bigger systems of the times. We expected to sell 5000 1401's but eventually installed more than 12,000. The 1401 led IBM into the computing big time, bringing to the company a much broader set of systems customers.

On the scientific side, the 7090 was a transistorized version of the 704 and 709, just like the 7080 was a transistorized version of its vacuum tube predecessor. Something like 300 7090's machines were installed. They were profitable and were very popular in the scientific and aerospace communities and that had something to do with some of the arguments that arose during System/360's design.

There had been a gap in the middle of IBM's scientific product line and a lot of clamor came from the demanding sales force for small scientific computers. A group at Poughkeepsie developed a machine called the 1620. However, instead of a small binary design they produced a decimal design. Its rental was $1600 making it the first IBM system with a rental price smaller than its serial number. We sold more than a thousand of those systems to the fledgling minicomputer area.

The 7030 was a special machine. Years earlier, Dr. Edward Teller had wanted a new scientific system for three- dimensional hydrodynamic calculations, and Dr. Teller talked about his need to IBM super salesman Cuthbert Hurd. Dr. Hurd had guessed that such a system might take a couple of years to build, might cost $2.5 million and might run at one or two million instructions per second. Dr. Teller went to Congress and got the funds. And so a small group that included John Griffith and Gene Amdahl, worked on a design that we called LARC for Livermore Automatic Reaction Calculator. A Univac team also worked on their version of LARC. We thought we had a great design and were on the way out the door of the Poughkeepsie laboratory to present our design to Dr. Teller when Ralph Palmer stopped us and said, "It's a mistake." Transistor technology was changing rapidly, and we were going to build this system with point contact transistors or surface barrier transistors, the semiconductors that produced the best speed in the early days. Palmer had noticed the newly invented diffusion process promised better control of the speed of semiconductors and thought it would be a mistake to build the LARC system with obsolete semiconductors and occupy the estimated 350 people required to build it. So Palmer, to our dismay, forced us to tell Livermore's Lou Nofrey and Dr. Edward Teller that we had decided not to build the design we had worked on. We showed Livermore our design approach to illustrate the kind of system we were capable of building but said, "We are not going to build that machine for you; we want to build something better! We do not know precisely what it will take but we think it will be another million dollars and another year, and we do not know how fast it will run but we would like to shoot for ten million instructions per second." So Dr. Teller bought the Univac machine, and we went back to lick our wounds.

Later, with the Univac LARC system commencing development for the AEC and the able Sperry salesmen selling it, IBM concluded that we had better fund a new system ourselves. The thesis was to build the fastest system. It was internally called Project Stretch, for stretching the technology. we did design the Stretch system ultimately producing a total of seven. Its IBM type number was the 7030 and it was the fastest system in the world for a period. The 7030 was quite expensive to build, costing IBM tens of millions of dollars. However the technology and the architecture that flowed from Stretch later had important influences. All of us in the IBM development community have a soft spot in our hearts for taking on such "one-of-a-kind, break-the-sound-barrier" projects.

It would be relevant to describe the company organization in the 1950's when IBM was still very small. Although it was a $200 million firm, there was one vice president for engineering and he handled all engineering business such as the national interest business, supplies, typewriters and electric accounting machines, the largest engineering activity and, the few engineering tasks in electronic computers. And so it was with manufacturing with one VP overseeing all aspects and so it was with marketing that a VP oversaw both sales and service. That was an inappropriate structure for the growing IBM which crossed a billion dollars of sales in 1957, thus the organization was changed. A major reorganization started in 1955 and in four years the change was completed. In essence, the company decentralized and formed new divisions.

The World Trade Corporation, that had started years earlier was beginning to grow. It had its own marketing for the countries in which IBM was present, its own service, its own manufacturing and its own development with its own laboratories and engineers. World Trade had rationalized their countries needed products that were different from what the Americans were producing, so it set out to build its own products for its customers.

In the mainstream was a senior vice president for data processing, T Vincent Learson. His organization was set up in a new structure consisting of three divisions. The General Products Division in Endicott, New York and San Jose, California had the mission of developing and manufacturing products with rentals up to $10,000 per month. In Poughkeepsie, New York the mission of the Data Systems Division was the development and manufacture of systems renting above $10,000 per month. The Data Processing Division handled sales and service and was headed by a super professional, Gilbert E. Jones. In its heyday it was as fine a marketing force as ever existed.

One important point: In this structure the financial books were controlled by the product divisions; marketing and service were run on apporionments that were doled out by the product divisions. Thus the product divisions did the market forecast; set prices and had general responsibility for the financial health of the products they produced.

Now let us consider the IBM product offerings at the time System/360 development was commencing. There we were in 1960 with six families of new systems, most of them doing well. The 7070 was not selling as well as we had hoped but the rest were selling well and some, such as the 1401, far exceeding our forecasts.

The major reorganization had just been completed in 1959 when Tom Watson, Jr. called the new senior management together and, in what I thought was real vision, said that our new products should serve IBM well but we should start thinking about where we are going in the future and should have someone start working on that future. His conclusion was the Data Systems Division would be given that mission.

Now some irony: the General Products Division, which had won the internal competition to build the 7070 was struggling with that system's design and release to manufacturing. It was late in schedule and its architectural complexity was affecting programming.

IBM's Immediate Products to Strengthen the Product Line: 1961- 1963.

However in the major reorganization of the 1950's as luck would have it, the Data Systems Division took over responsibility for the 7070 and its problems. Some of DSD's leaders thought the best thing to do was to get rid of 7070 so they started a project in Poughkeepsie to build a better system. The development leader in Poughkeepsie, Steven Dunwell, gave a simple charge to the engineers under him: "I want a machine that is twice as fast as the 7070, at half the cost." He had another little codicil on his charge: he wanted it packaged in one rollagon, which was one of the packages we used then in larger systems.

So the people in Poughkeepsie began the new design. Bolstered by Tom Watson's assignment of a corporate mission to plan the next series, they expanded their 7070 replacement into a family called the 8000 series.

The proposed 8106 was the specific product Poughkeepsie conceived to replace the 7070, and it was furthest along. As a matter of fact, it was being prepared for announcement in March 1961. To fulfill their worldwide mission, Poughkeepsie quickly planned other systems around the 8106. They added a scientific attachment called the 8108; it was not a standalone machine-you had to buy an 8106.

Burroughs was working on a technique called push down stacks and Polish notation and that concept enamored some of our people. Thus Poughkeepsie decided to build an analogous high performance system called the 8112. The General Products group was so successful with the 1401 that they did not want anything to do with the 8000 series but Poughkeepsie required small systems to handle peripheral management and to provide growth for their bigger systems. Therefore, they wanted a small commercial machine and started a design called the 8103, a small business computer. To fill the gap in the scientific area, Poughkeepsie proposed a machine called the 8104. These systems had some architectural similarities but, by and large, were quite dissimilar and that was perhaps the fatal flaw.

Other groups in IBM were working away too. The General Products Division, with their 1401 success, had planned to take that machine in all directions, down and up. They proposed a 14016, 1440, 1410 and 7010. They had a 1620 model II, and because of the success of the 1401 and 1620's it appeared that General Products was headed for success with a line of systems competing with Data Systems' proposed 8000 series.

The World Trade Corporation did not like the 1620, it was a decimal machine and World Trade wanted a small binary machine. Thus the Hursley England Laboratory started a design of a 48-bit, small binary machine called SCAMP-I, a credible machine that might have succeeded had it proceeded. Unhappily, the computer demand in Europe in those days could not generate enough volume to pay SCAMP's way, so the machine was in financial trouble. The aggressive Hursley Laboratory then said, "We can build a faster version called SCAMP-II on the SCAMP-I base, get more volume and fix the business case." They tried just that but it was not enough to fix the business case. So, undaunted, they hypothesized a business version of SCAMP called SCAMP-III, and were evaluating that approach.

In net then, World Trade had its evolutionary plan, Data Systems had the corporate mission and its 8000 series plans and General Products had its plans based on the success of the 1620 and the 1401. All the camps were in competition. It appeared as if a time would come when a customer would call up and say, "I would like to hear about an IBM machine," and three salesmen would get stuck in the door waving their catalogues saying, "Don't listen to him, listen to me."

My role in this came in January 1961 when Vin Learson asked me to leave Endicott, where I was working on the 1401, 1620 and the 1410, and to go over to Endicott's rivals in Poughkeepsie. His instructions were simple: "Look at that 8000 series-if it is right, build it; if it is not right, build what is right." That is about the length of the discussion I had with Learson.

One of the problems we had with all those architecturally dissimilar systems, was that peripherals had to be customized by family. If you wanted to build a peripheral that was optimized for parallel binary machines, that was tough to justify businesswise. If you were going to build something that was serial by character for commercial machine, that was another design. None of these systems had enough volume to sustain new investment in a variety of types of peripherals, so the peripheral groups in San Jose, Endicott and Poughkeepsie worked at what they believed best to build, and the system adapted those devices to the processors.

Since most of the technology work was going into the processors the peripherals were not keeping pace with the processors. It was possible to go from one processor to another and get 100 percent gain in internal performance, but because of slow peripherals a user might realize only a 10 or 15 percent gain in thruput performance and that is before you take programming into account.

Circuit technology was also different by type of machine. Here I must say that Ralph Palmer and senior development management had strived to standardize our semiconductors from the beginning. Previously in IBM every project had its own designers who would design the circuits for their projects, optimizing their products for their intended applications. In 1955 Ralph Palmer established central circuit-design laboratories, with the centralized group providing circuits to the systems groups. It caused much disagreement in the laboratories but, in hindsight, it was the right decision.

To aid standardization we designed a printed circuit card called SMS - the Standard Modular System. One card was approximately the size of your hand and held one circuit of discrete transistors, resistors, diodes and capacitors. We developed a lot of automated equipment to insert components, to solder them in place and to test the cards. In the early days of transistors and the Standard Modular System, the management theory was that if we did it right, about a hundred of these SMS card types would serve all the IBM systems which would be just fine for service, service training, engineering refinement and further evolution.

However by 1960, the requirement had exploded out of control and had grown to more than 2500 card types. The Standard Modular System plan had missed its target significantly. There were so many card types the circuit engineering force spent its time designing new circuits. And, of course, field inventory, field engineer training, and such things were expensive and complex.

Perhaps the worst problem that plagued our many types of systems was programming. In 1960, during the heyday of the 1600 and the 7000 series, our programming budget was $5 million, less than five percent of the development budget. With so many types of architectures, not only did we have to produce FORTRAN for each type of architecture but there had to be a FORTRAN for the disk version of the 7090, and one for the tape version of the 7090 as well as special assemblers and utilities. We were in trouble with respect to programming in 1960 and we knew it.

Moreover, we had split our customers' computing with scientific and business machines. Boeing is a typical example. It had two very able yet separate computing shops-one had 7080's, one had 7090's- vying for funds, vying for applications and vying for people. What really was happening, we perceived, was that business systems needed more of the logical and computing abilities of the scientific systems, and the scientific operations needed more of the variable field length and alphanumeric capabilities of the business systems. We had unwittingly put our customers into two camps and the camps were competing.

The user programming investment was high and growing rapidly, and our customers had sent us a signal with the 7070: no matter how powerful the architecture, no matter how much better the price-performance ratio was in contrast to older systems, they were not going to make the move. Most users could not afford to convert and did not.

In 1960 most IBM development resources went into the evolution and propagation of processors. Only a small amount went into peripheral research and enhancements. Most peripheral R&D went into tapes, a bit into disks and printers, and a tiny amount - $5 million in 1960-for programming.

Thus, with all these problems, in considering the 8000 series in 1960, we concluded it had frailties such as the incompatibilities between the architectures themselves, had other missing elements in the program and were planning implementation in existing technology. In May 1961, a decision was made to build a new family of systems in new technology. Each system in the family would be equally adaptable to business and scientific use. And while it was easy to produce machines that were upward compatible, we were going to try and design the new systems to be both upward and downward compatible. Thus if any systems had the required peripherals and the amount of memory specified by the programming, it could run the same programs, whether it was a big machine or a small one. More importantly, the approach unfettered programming from the specific systems themselves. The entry-level programming could run on the whole family, and large systems programming-more complex programming with higher function-could also run on the whole family.

And to fix the I/O problem, the new systems' thesis was standard interfaces for peripherals. We decided to have the peripheral devices adapt to the standard interfaces so that control programming would not have to be changed extraordinarily by new peripherals, and we hoped the new peripherals could achieve high volumes.

Lastly, the plan was to build the new systems in a new technology that was under development in IBM. Internally it was called the Compact technology, later named SLT-Solid Logic Technology. Basically, it was a hybrid, micro- miniaturized technology which, instead of using the palm-sized SMS card to package the circuits, Compact used fingernail-sized chips, each containing a single circuit. Erich Bloch, John Gibson and I agonized a lot in 1961 about whether we should go to large scale integration instead of pursuing the hybrid micro-miniaturized technology. Fortunately, we elected to build what we had in hand. Heavy investment went into automating the production of SIT technology and production was very sophisticated. Significant volumes were turned out at high quality and low cost.

The architecture of the systems had a decimal and variable field length base structure with optional binary and floating point. Each system could perform scientific as well as business calculations and we also tried to design in the basics needed to allow us to expand to new applications such as real time or event driven applications as they unfolded.

Another problem: IBM has an aggressive sales force and they were paid largely on commissions. Our salespersons did receive a base amount which would buy baloney sandwiches, but if they wanted to eat steak, they had to sell. Our sales force's long range viewpoint was that "tomorrow is too long." They certainly had a tough time waiting for a few months, let alone a few years. However, anything as significant as shifting gears to a new technology, new architecture and new programming was going to take a lot of time. We estimated that we would announce in 1964. It turns out we did announce in 1964 and shipped in 1965. But in 1961, such a delay seemed like an eternity to the sales force.

In the meantime Seymour Cray at CDC and lots of able companies were beginning to succeed, bringing out competitors for the IBM product lines. Our sales force felt their homes were burning down and they wanted some solutions quickly. So we put in place some programs I called "temporizers"; I hate the word, but that is what we called them then. The project consisted of extensions to the current product lines. There was to be a higher speed version of the 7090, called the 7094, which turned out to be so successful that we built a 7094-2 and we actually worked on a 7094-3. Two new extensions of the 7070 were built-the 7072 and the 7074-intended to aid the lagging 7070 sales.

A bigger version of the 1410 was built for 1401 growth, the 7010. A 1620 Model 2 was built, and for that gap in the small scientific area, two systems were built that were related to the 7090 architecture-the 7040 and 7044.

All these systems were undertaken starting in mid-1961. Some were announced in 1962 and the rest by May of 1963. IBM suffered competitive losses but we were able to keep the sales force alive during the time the gears were being shifted to System/360.

In net: System/360 solutions in terms of the problem was to standardize peripheral interfaces across the system; the circuit technology used throughout the system was the new solid- logic technology; programming was independent of the hardware, and the scientific and business split was solved by integrating into one system the capability of addressing both classes.

The key issue of 1962-63 became one of program conversion. For a long time Fred Brooks, Gene Amdahl, John Griffith and others worked on how to do this. The first thought was to have machine translation. Bright people worked on a conversion program that would allow one to dump a program in a hopper and have the conversion produced run effectively on the new architecture System/360. After a couple of years of hard work and several million dollars of investment, we concluded automatic conversion was not going to make it. The theory then was that we had better back off to machineassisted translation where we would translate as much as we could and signal the items that had to be handled manually.

We knew our customers were not going to convert manually; we had to have a tool. Necessity breeds invention, and a couple of professionals found the solution. We found that if we examined the 1401's registers and data flow in the light of the 360, the 360 had all the registers and more, and all the data paths and more. Since we had decided to use some of Professor Wilkes' work in the controls of these machines, namely read-only memory instead of hard-wired logic, the controls were vastly simplified. Thus it was relatively easy to add to a 360 machine the instruction set for a 1401 and literally throw a switch so the System/360 would run credibly as a 1401. Emulation proved out for the 1401, 7070, 7090, and 7080- fortunately for IBM.

Systems running in emulation mode did not run at full 360 performance, of course. But, by and large, through the combination of read-only memories for control that let us add the instruction repertoires of the older machines, the 360 machines did take on the form of the older systems and customers could run the old machines' programs with reasonable priceperformance and then convert at their leisure to the newer architecture when they wanted. But believe it or not, some users are still running in emulation mode after all these years.

1962 was a period in which we found ourselves asking can we make it? Can we design the family? For a while it appeared that we could not design a processor that was inexpensive enough at the low end while containing the instructions of the big machines; similarly for a processor at the high end, would their performance be limited by staying compatible?

But senior management realized that if we produced a five-times 1401 and Honeywell produced a four-times 1401, the whole question would be quickly reduced to plant capacity. Honeywell might sell 5000, we might sell 5000, and conceivably there would be a price war. Worse, the 1401, invented years earlier, was inadequate for future applications.

In contrast to the existing product lines, there were so many attributes in the new product family that in February 1964 IBM decided to go ahead. We announced System/360 on April 7, 1964. We announced five machines; the Model 30 was developed in Endicott and the Model 40 was developed in Hursley England. As a side point, World Trade wanted to play a role in the 360 development. Its labs were full of bright people, but young and inexperienced, thus I wanted to give them supporting roles. However, Vin Learson said "Absolutely not. They have to have a head-held-high role; we want to give them a whole system." So we did. We exported a number of U. S. people to help Hursley, and after that Hursley became one of the senior labs in IBM's development community.

Poughkeepsie developed the Models 50, 60 and 62, and Model 70.

Later, through the last part of the 1960's, there were successors and additions announced: the entry System 20 and the 22, the 25, and a scientific optimization Model 44. Some new memory came into the 65, which replaced the 60 and the 62, and the 75 with the new memories replaced the 70.

The 360 model 67 grew out of MIT's criticism of System/360. MIT scientists were important in computer research, and we wanted to be certain we stayed close to MIT's thinking. And during this period, as busy as we were, 360 design people would go occasionally to MIT However, in retrospect, MIT did not hear us, we did not hear them, and I presume we did not speak clearly enough to them.

When the 360 system was announced on April 7, we all settled down to the happy task of making it happen. But on June 6, 1964, I traveled to MIT to see what they thought of 360, which by then had been announced for a couple of months. To my dismay Professors Corbato and Fano told me that they did not like System/360.

Three of MIT's four criticisms were trivial and could have been fixed quickly but, criticism one was deep in the concrete and that was MIT's view.., that time sharing was just around the corner, thus dynamic, address translation would be a fundamental part of any system's architecture in the future. Without it, management of the storage by the programmers would be an impossibility.

There was some debate in IBM, but I decided that MIT was right, and we had missed it. It took us several years, but we did fix it and finally got dynamic address translation across the family. However, back in 1965-66, we produced a special version of the Model 65 called the Model 67 which was built for leading-edge customers like Bell Labs that wanted time sharing and demanded dynamic address translation.

Unhappily for us, MIT decided to buy a General Electric machine and not the 67 that we were designing to supplement the 360 family and answer their requirements. Through the 1960's, the only 360 machine that had dynamic address translation was the Model 67. A special version of that design, called the 9020, became the system used in the FAA's enroute traffic control system.

We thought in those days we would be lucky if the series would last one generation-3, 4 or 5 years-and if we were really lucky it would last 8 or 10 years. However System/360 has lasted 20 years, and we are working now to extend its life into the 90's. Possibly it will not make it, but the durability of the 360 architecture has far surpassed our expectations.

By the late 1960's, technology had marched on to the point that instead of one circuit per solid logic chip, we could do three or four circuits per chip: the early days of large-scale integration. So we produced a family of follow on 360 systems: the 115, 125, 138, 148, 158 and 168 and, in between, there is some detail of what were called "vanilla" machines that I will skip. The bottom line is that all these machines had dynamic address translation and our control programming was substantially evolved to accommodate virtual systems capability.

The mid-range and high-performance systems of the 1970's were all direct members of the 360 architectural family. And since 1979 the 43XX machines and the 308X's were added and they are all members of the 360 architecture. These systems, over the years, have produced more than $100 billion of revenue. IBM margin has stayed strong even through the thick and thin of such periods such as the recessions of 1971 and 1975.

I said earlier that we tried to design into the roots of System/360 the abilities that would let us work in future applications. One that we sensed clearly in 1962 and '63 was teleprocessing, for it was beginning during that period. But we did not get our hands enough around teleprocessing to know just what to do, so we put hooks into System/360 to add teleprocessing capabilities later.

Our estimate was that in the United States we would sell 2500 of the 40, 50, 60 and 70 systems, and by 1970 a third of those would have remote terminals and thus require communications, hardware and programming. What actually happened, fortunately for IBM, was that we sold twice as many of those systems as we had expected by 1970, and by 1968 we had already passed in teleprocessing what we had expected to reach by the end of 1970. And by 1970, we had sold two and a half times what we had expected to sell in terms of teleprocessing.

In hindsight, just building those 360 machines and the complexities of the technology, new peripherals and control programming so consumed our resources that we really did not tend swiftly enough to communications. And that explains the alphabet soup that existed in 1970 teleprocessing for one laboratory or another would develop a piece and a customer would produce something else and the assemblage was inadequate and inconsistent for teleprocessing in 1970.

Thus, starting in the early 1970's, we set out to do the same thing to the communications subsystem that we had done to the central processing subsystem. It was called Systems Network Architecture (SNA), and some of you may be familiar with SNA. We shipped SNA first in 1974 and, it has been generally accepted by the International Standards Organization as an architecture that straightens out the protocols, disciplines and structures of the communications subsystem.

In 1973, when we were finishing work on SNA, our hope was that we might install 3500 SNA systems worldwide early in the 80's. Last year an IBM team gathered to celebrate our 10,000th SNA customer.

At present in the hey-day of PC's and the exploding world of work stations, we are talking in terms of hundreds of thousands of SNA installations.

SNA has had a succession of sophisticated additions to the structure, the features you would expect once a base is in place; alternate routing in the case of line outages, dynamic reconfiguration non-IBM terminal attachment, and those types of abilities.

There is an explosion taking place in computers and communications. Today we find computers connected to computers by communication lines and control units connected by communication lines to hundreds and thousands of terminals. Then, of course, there are minicomputers pioneered by Digital. Whether it is realtime applications, batch applications or interactive applications, minicomputers also require communications from distant terminals, and more and more, these terminals need access to central data bases and vice versa. Thus there is great need for computer communications.

If I would characterize where we are today in allocating our resources, we spend a good deal more on communications and still spend a handsome amount on programming and peripherals.

The computer-communications explosion caused us to decide to do something more significant in communications.

We worried about AT&T for, if they controlled all communications and also provided computers, IBM might be at a disadvantage. Thus we invested in a communications satellite company that is providing new communication services. It will be a good business in its own right and is bringing new communication capabilities to teleprocessing users, keeping pressure on the telephone companies. We think that is good for the industry.

How did general management operate? First there was a strategically minded management in the 1960's. Tom Watson assigned a team to work on the next generation.

A broad direction was set but the senior management delegated detail; they did not strive to manage the architecture. They heard the debates and worked to resolve problems but never stepped in to dictate designs such as 36-bit words.

The 360 undertaking stressed IBM to the limits and senior management organized and reorganized IBM to meet the needs of the times.

Lastly I must say that through a lot of countering viewpoints, senior management such as Tom Watson, V.P. Learson and Al Williams, had a lot of tenacity and did risk a lot.

As to whether it was worth it, I will just say that from the period 1964 to 1980, the profit after tax on 360 systems was far greater than the total sales we had anticipated back in 1964. This System/360 was an outstanding business success. More importantly, it gave us the foundation to move resources into new peripherals, to do the things like SNA and all that went with SNA in terminals and teleprocessing, to specialize in certain industry areas and to diversify into businesses such as satellites.

It has also given us a new complexity for in the 1960's came the compatible peripheral competitors. A small company in Oklahoma, Telex, started making copies of IBM's magnetic tape. A number of customers bought the copies. And soon, manufacturers produced copies of our disks, multiplexers and main memory and by the 1970's we saw copies of our terminals and finally, the piece de resistance, compatible central processor from Fujitsu, Hitachi, Amdahl, Magnusson and others.

Those copies were expected. When we started to work on System/360 our rationalization was that, in the face of copies we had to insure that IBM was constantly the best, that we had the best technology and the best programming and the best price performance. Those ideas sold in IBM and we still believe it.

One negative consequence was the anti-trust litigation that was very costly and stressful.

In the last days of Lyndon Johnson's administration a law suit was filed by the Department of Justice. Also, Telex had filed suit saying that we had damaged them with our "predatory" practices. We filed against Telex for stealing and in a curious decision in 1972, the District Court in Tulsa found for both companies. It found Telex guilty of stealing and fined them $20 million and found us guilty of damaging Telex and fined us $120 million. After trebling under U. S. antitrust law that fine went to $360 million.

At the end of 1972 IBM stock went from $365 to $140.

IBM System/360 in Conclusion

Immediately other companies thought they had been damaged too and filed their own law suits - TransAmerica, Memorex, Calcomp, and others. So, with much senior management and lawyers time expended, IBM went through the gauntlet of several anti-trust trials. That story is over for now, and I hope forever. We won every case on the merits and, recently, the last one, the TransAmerica case went to the Supreme Court which refused to hear it, thus upholding the lower court's decision. And a little over a year ago, the government dropped their anti-trust suit as being without merit. So that enormous weight has been lifted and we are back to getting on with life.

Yet the debate goes on that, had we not standardized and designed the System/360, we would not have had these kinds of copies, and we woula not have had those lawsuits, and thus would not have had such difficulties. Thus, was it all worth it?

Of course my bias is that the driver of our products is the end user, and we have an accountability to that user. We also have an accountability to conduct ourselves in an ethical manner. Overall I believe devotedly the 360 decision was the right decision.

I can tell you that if I were faced with that decision today, we would make the 360 decision again, although I am certain it would be much tougher these days.

The net is: System/360 was conceived, born of a need, weathered a lot of tough gauntlets and went on to be a success for IBM and to be a significant part of the computer industry.

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The Computer Museum Report

Number 10 ---- Fall 1984

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The Director's Letter

In our countdown to opening the Museum, I am pleased to have the opportunity via the report to reflect on the evolution of the Museum. Five years ago, I was charged with the task of creating a "computer museum." The only models at that time were IBM's dismantled history wall done by Charles Eames in the sixties, the small exhibit of historic machines at the Smithsonian, and the interactive and historic collections at the Science Museum in London. None of these could be collected and brought back. And I felt as though I had been told to "Go fetch a rock." Every time I brought an idea back, the feedback was quick: "That's not the rock," or "How did you ever get that-it's just great."

Two and a half years ago, on June 10, 1982, The Computer Museum opened its doors for the first time: we had 50 Founders, 200 members and 3,000 square feet of dedicated exhibit space. Our goals were to develop an international collection, create exciting exhibitions, sponsor educational programs, and attract a worldwide membership. On June 24, 1984, at the end of our Founding period, we will boast 504 individuals and corporate Founders. I am glad to extend special thanks to the individuals listed on the front cover and the corporations listed on the back cover helping to found the Museum.

The Second Opening

On Wednesday, November 14, 1984 at 11:00 a.m., the Museum will formally open its doors a second time to the public. This time we will have 16,000 square feet of exhibitions of both historic computers and state-of-the-art interactive displays; another 8,000 square feet of exhibit space and 4,000 square feet for library/study collections will be developed later. As we approach our opening we can be pleased that we have by far the largest exhibition area devoted to computing and information processing at any museum.

Let me give you a brief tour of our plans for the exhibitions: After rising to the Museum on a large, glass-enclosed elevator overlooking downtown Boston, the visitor is confronted by the Whirlwind, a vacuum tube computer that seems to go on forever.

Going around the corner, the visitor enters the SAGE computer room. Here the major components of the world's largest and longest lived computer simulate their installed environment. The visitor can "start" the console and see its banks of lights cycle-up. Beside each component, such as the 30-foot-long accumulator, today's equivalent chip (or part of a chip) has been placed for comparison. This arrangement reinforces an awareness of decreasing size and power and increasing programming capabilities.

For the history buff, a year-by-year timeline from 1950 to 1970 shows the fundamental inventions, the major computers, major software developments and benchmark applications.

The CW Communications "See It Then" theater shows films of operational computers, starting in the 1920's and ending in the 1960's with the IBM Stretch. The films are complemented by a 1965 IBM 1401 computer room, where the visitor can punch cards, and an operating PDP-89, the classic (but now very slow) minicomputer.

The evolution of Seymour Cray's work illustrates a single hardware contributor and his philosophy. The story begins with the NTDS-17 that he built for the Navy at UNIVAC in Minneapolis, which Greg Mellen, who is still at Sperry Univac, helped the Museum acquire; after that Cray built the Little Character, his first machine at CDC, presented by Control Data Corporation; then to the 6600, Serial Number 1, presented by Lawrence Livermore Laboratories; and finally to components of a Cray I, presented by the Cray Corporation. We have two videotapes of Seymour Cray, one from Lawrence Livermore Laboratories and another given to us by Joe Clarke, a former employee of CDC, who bought a two inch video tape player at a company sale and found on it a tape of Seymour Cray.

The next gallery focuses on chips and their place in the computer revolution, and the process of manufacturing computers. The inside of the "black box" is revealed, and an important, hidden part of the process is illustrated.

This collection of personal computers goes back to the very first one, the 1962 LINC, and extends to the latest models. The ring of live machines, each showing off an aspect of its special input/output, include DECTALK, a touch sensitive screen HP 150 and others.

The final gallery, is devoted to "the computer and the image." Here, the visitor will be able to explore image processing by computer, such as evaluation of landsat data, and image creation by computer, such as computer-aided design. Without much trouble, the visitor could spend two hours in this room experimenting and viewing.

The exhibits are only the tip of the iceberg of our collection of artifacts, working machines, software, documentation, photographs and films. The listing in this report represents one year's accumulation and the collection is rapidly growing.

The Evolving Board of Directors

At the first meeting of the board of directors in 1982, two decisions were made: one was to have non-renewable four-year terms and the other was to limit the number to 24 people. This year five directors retired, I was made an ex-officio director, and five new directors were elected.

The five retiring directors each played a significant role in our growth to date: Charles Bachman served as chairman of the executive committee through our critical first two years; Andrew Knowles provided our initial space in Marlboro; Robert Noyce was key in starting our semiconductor collection and gave a wonderful lecture at our pre-preview party; Michael Spock, director of the Children's Museum, had the idea of our move to the Wharf and continues to counsel us on a day-to-day basis as our closest neighbor; and the Honorable Paul Tsongas helped bring us recognition at a national level.

The new directors bring a new set of talents. Bill Poduska, the new chairman of the board, is chief executive officer and chairman of the board of Apollo Computer, Inc. which he founded in 1980. He came to MIT as an undergraduate and stayed through a Ph.D. in electrical engineering, which he taught for four years. Then he went on to become the director of the Honeywell Information Science Center before founding Prime Computer and Apollo Computer.

Mitch Kapor, president and co-founder of Lotus Development Corporation, looks at the role of computers from the point of view of a non-technical user. A pyschology major from Yale with what he calls "three-quarters of a masters degree" from MIT's Sloan School of Management, he developed VisiPlot and VisiTrend for VisiCorp before working on " 1-2-3," the business applications program for personal computers, that became the basis for Lotus. Mitch has expressed his concern for the end user, saying, "When we stop listening we will cease to be viable." This is equally true for the Museum when we open our doors to the public.

Dr. Koji Kobayashi, chairman and chief executive officer of NEC Corporation, began his life-long career with them in 1929. NEC preserved Japan's first transistor business computer the NEAC 2201 which they agreed to give to the Museum. This represents an important acquisition in our goal to develop an international collection. Dr. Kobayashi is also interested in the current technology, especially communications and computers, and will provide an important link to Japan.

Dr. Arthur P Molella is chairman of the history of science and technology department at The National Museum of American History Smithsonian Institution. Specialized museums, such as ours, have an important symbiotic relationship with the Smithsonian. We can focus on a single subject, collect, carry out research and prepare exhibitions. At the Smithsonian, Arthur has to trade off all aspects of science and technology and allocate appropriate space and personnel.

We intend to help each other, the Smithsonian has already loaned several important pieces from their collection for our opening exhibition. And when the new Smithsonian exhibit on computing opens, we will help them.

Dr. An Wang, chairman of the board and chief executive officer of Wang Laboratories, Inc., is one of the computer pioneers. He invented the magnetic pulse controlling device for the Harvard Mark IV which will be on display in the timeline planned for our opening exhibition. Wang not ony founded Wang Laboratories, Inc. but also the Wang Institute of Graduate Studies in 1979.

Since 1982, the course of The Computer Museum has changed in ways that I would never have predicted, but new directions that, in retrospect, always made sense. This distinguished new class of directors will help the Museum become a strong institution as it opens to the public.

Gwen Bell

The Apple I

-by Brenda A. Erie

When the Museum opens at its new quarters in downtown Boston on November 14th, 1984 an Apple I board will be part of the Museum's Personal Computer exhibit. Surrounded by a ring of state-of-the-art operational machines, the Apple I board will be exhibited with other personal computer ancestors such as the Altair and the Xerox Alto.

It is too difficult to put a price tag on the Apple I's current value because "only 210 to 220 Apple I's were ever manufactured," according to Stacey Farmer, of Apple Computer, Inc. This reliable microcomputer, which needed little assembly, was built in 1975 by Apple cofounders Steven P Jobs and Stephen G. Wozniak. Primarily bought by computer experimenters and home computer novices the Apple I could be used for developing programs, playing games or running BASIC.

When the Apple I was inaugurated into the marketplace, the "two Steve's," (as they were nicknamed by their employees) had already established a design philosophy that still exists today at Apple - dedication to making their computers easy to use, understandable and inexpensive. They also recognized the need to incorporate suggestions from Apple I users to improve the production and sales of the machine.

The home computer market liked the Apple I because it was easy to assemble unlike some of the kits that were around in the mid-1970's. Rich Travis, a sales representative at the Sunshine Computer Company in Southern California did not directly promote the Apple I in 1977, but made the machine "easy to buy" for his customers because they were "looking for a complete, ready-to-run system that was inexpensive."

The Apple I was sold at computer stores throughout the United States. In 1977, Kilobaud Magazine ran an article by Sheila Clarke a computer hobbyist writer who found that owning the Apple I did not "require you to be either an electronics buff or a millionaire."

For instance if you had walked into the Byte Computer Store in San Jose, California to purchase an Apple I in 1977, you would have gotten a fullyguaranteed computer kit for $666.66 that included: a printed circuit board with video terminal electronics, 8K bytes of RAM, 4 regulated power supplies, a keyboard interface and a hex monitor in PROM.

However, other purchases were also required in order to get your Apple I operating. These totaled $122.00 and included: an ASCII keyboard, a video monitor (if you didn't use your own TV set), and two transformers. If you did use your own television, a simple modification was required like a Pixe-verter or switch box and an rf modulator. In order to store programs, a two inch high cassette interface (ACI) was also available which came fully assembled and burned- in with a tape of APPLE BASIC for $75.00. Jobs and Wozniak both agreed that BASIC at this time was the language of the people because it was easy to use.

In 1977, Apple I advertisements claimed that, "unlike many other cassette boards on the marketplace, ours works every time." So if you also bought a tape recorder you were in luck because the Apple I worked reliably with almost any inexpensive audio-grade cassette recorder. Your total cost for the machine, $903.66.

Relatively few Apple I's were sold compared to personal computers on the market today. However, the Apple I gained enough popularity because it was essentially "hassle free" and could be purchased for under $1, 000. Hobbyists, home computing novices and the computer store dealers themselves applauded its reliability.

It was this microcomputer, the Apple I that enabled Apple Computer, Inc. to quicky turn from a small, single product private company to the multiproduct, multi-national, public company that it is today. As the Apple I's sales increased in 1977, Jobs and Wozniak began to spend much time perfecting the design of the Apple I and their future product the Apple II. But as the company bloomed, it was necessary for Jobs and Wozniak to go to the outside for help.

They recruited A.C. Markkula who had been marketing manager at Intel. He was fascinated with what both Jobs and Wozniak had already accomplished. To show his confidence in the duo he put up $91, 000, secured a credit line, and then found $600,000 from other venture capitalists to help put Apple Computer Company on its feet. Shortly after, in May 1977, Markkula became chairman of the board, and Michael Scott, who took a 50 percent pay cut to join Apple from National Semiconductor became the company's first president.

This Apple 1 board will be part of the Museum's Personal Computer exhibit opening November 14, 1984. Apple Computer, Inc. co-founders Steven P. Jobs and Stephen G. Wozniak designed the Apple 1 in 1975 to meet the requirements of computer hobbyists. Priced at $666.66, it met their needs as an easy-to-use computer system that was inexpensive.

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The Computer Museum Report

Volume 11 ---- Winter 1984/85

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The Director's Letter

It's great to be open again!

About 1500 people came to the opening on November 13th, including 100 from outside of Boston. Masateru Takagi, Vice President of NEC in Japan, traveled the longest distance to represent Dr. Kobayashi at this historic event.

The formal "ribbon cutting" was in keeping with the Museum. "Shag" Graetz, who worked night and day the last week to get the PDP-1 up and running, prepared the program that punched the paper tape reading "The Computer Museum Grand Re-Opening 13 November 1984." The students at Minuteman Technical High School then programmed an Apple II to control a robot arm that cut the 1960-era tape. The new exhibitions at the Museum range from vacuum-tube computing to the uses of the new personal computers, professional workstations, and computer networks.

Outside Entrance

Visitors at the opening.

The re-opening and re-birth of The Computer Museum took a long time in the making. Marlboro provided an excellent beta-test site for historic exhibits but gave us little experience about interactive computing within exhibits.

After the Board of Directors approved the move in May 1983, planning started immediately. A team of "developers" was put together. Dr. Oliver Strimpel, then Curator of Mathematics, Computing, and Navigation at The Science Museum, London, agreed to come as Visiting Curator and develop a highly interactive gallery devoted to computer graphics and image processing. At the completion of this work, Oliver agreed to stay on as the Curator of the Museum. Oliver subdivided the tasks in the image gallery with Geoffrey Dutton and Andrew Kristoffy as developers.

I undertook the role of curator of the rest of the exhibitions with "developers" for each segment: Paul Ceruzzi (who is now at the Air and Space Museum) on the 1950-69 Timeline; Beth Parkhurst on the integrated circuit and Apollo Guidance Computer exhibits; Carl

Sprague on the "See It Then Theatre"; Meredith Stelling on the ANFS/Q7, SAGE, and UNIVAC exhibits; Gregory Welch on the IBM 1401 Room, Seymour Cray, and Manufacturing exhibits; and Bill Wisheart on the personal computer exhibit.

Oliver, the developers and I then started to work with a broad set of advisors who helped us refine ideas, collect the materials and computers, and some of whom eventually worked on the actual programs and installations. The architectural firm of Crissman and Soloman were chosen to integrate the ideas of the developers with the existing structure of the 1880's wool warehouse and come up with suitable exhibition space. Meredith Stelling took on the role of supervising the contractors, Hawkins and Co., and the graphics designers, Maxwell Design.

When we worked out the schedule, all planning was to be complete by June 1, construction complete in early October, with a month for exhibit installation. It never worked that way. Everything happened at the end. And is still happening. When we opened with over half an acre of exhibits in five large rooms, each was about 70% complete. Over the winter, the exhibits will be finished and some will start to evolve even further as we watch how visitors are reacting.

By June 1, the developers had their scripts completed and then seriously sought to implement them. One exhibit that we knew we wanted to animate was on the Apollo Guidance Computer. Hewlett-Packard agreed to give us an HP-150 with a touch sensitive screen and the use of Tom Horth in their Andover facility as a consultant. Draper Laboratory's Malcolm Johnston coordinated the work of our summer intern, Andy Gerber, in order to ac- curately simulate the astronaut's console. But by July 1, the HP-150 had not appeared. Andy was more than ready to get started on the machine. Tom Horth came up with a loaner so that the project could begin in earnest. By mid-August the prototype program was tested and it was slow. Tom arranged to get us a faster compiler. Then, the actual machine came in September after Andy had gone back to MIT

Another interactive exhibit that we wanted from the outset was one that communicated the concept of "discernability," conveying the meaning of pixel sizes, grey levels, and false coloring in image processing. Masscomp agreed to take on this exhibit. Lorrin Gale, Vice President of Engineering, personally made two trips to the Museum with several programmers. The project was specified and Masscomp produced a special two terminal machine. Each terminal was connected to a tv camera that they supplied. One camera is focussed on the face of the visitor, who then can change the pixel size and grey levels of his own image. The other camera is focussed on the view of Boston. The visitor can then color in the grey levels to create an "Andy Warhol-like painting." The engineers at Masscomp got excited about this project (one that has little hope of ever being a product) and kept assuring us that it would be exactly what we specified. Oliver visited it at the plant three days before opening and was satisfied. Masscomp delivered the two exhibits exactly one hour before the preview for the Board of Directors!

Last July, Oliver, Geoff Dutton and I went to SIGGRAPH, where, among other things, we collected "the teapot" from Martin Newell and got lines on other exhibit material. As I write this on New Year's Day the "teapot" exhibit is not yet complete. Its components are numerous. Adage gave us a terminal connected via a fiber-optic cable, donated by Fibronics, to the VAX 750 contributed by Digital Equipment Corporation. The "teapot" simulation is still being programmed by Allan Sadoski, a volunteer from the Adage user group, and his 16-year old "hacker friend" Neil Day. They are spending most weekends at the Museum, providing a living, working exhibit. Parallel to this simulation, the Design and Production staff of The Children's Museum is building a stage set for the real teapot where its lighting can be manipulated manually. This should be complete in mid-winter.

IBM Fellow and Harvard Professor Benoit Mandelbrot became very excited about producing an interactive exhibit of his concept of fractals. He produced a program on the IBM XT but it lacked sufficient variation. A prolific author, he discovered, as we had, that an interactive exhibit needs to have a lot more variety than the illustrations within an article. A week prior to opening, the program was finally acceptable but we had no machine to run it on. Our two IBM XTs were committed to other programs. Dr. Mandelbrot arranged for another XT for this exhibit and it arrived (minus several critical parts) three days before the opening.

One exhibit that arrived complete and wonderful a full week before opening was a video of the view done by Dean Winkler and John Sanborn of VCA Teletronics. In August, they came up from New York and cavorted on top of the roof videotaping the view. They talked to us, looked at the logo and some of our concepts, and then spent over 200 midnight hours of editing with the very fancy frame-buffering equipment to produce a three-minute spectacular of the view popping out in different colors with the core plane logo flying over it and skyline circling a pyramid. In this case, the creators were given artistic freedom and went wild in making a very spectacular video. The equivalent spot made commercially would cost hundreds of thousands of dollars. Dean Winkler and John Sanborn will come up and explain to all how this was done in a talk on Sunday March 17.

Yes, it's great to be open. Three "beta-test" talks were given in December, and now the full schedule of talks for the spring appears on the inside back cover. These are planned for every Thursday night at 7 and Sunday at 4 from February 7 to April 28. The next issue of the Report will have an article on one of the December talks-a conversation between Steve Levy and some of the heroes featured in his book Hackers. For those of you who can't get to the talks, we'll try to bring you the very best in the Report.

Best wishes for the New Year.

Exhibits

Diagram

Whirlwind Entrance

Entrance into the Museum puts the visitor in Whirlwind's arithmetic units, which occupied a whole room in the Barta Building at MIT. The 16 bit word length, extending 32 feet, was partially determined by the width of the room.

The visitor enters into the Whirlwind computer-the first real-time stored pro- gram computer, so large that it took up a whole building. In a segment from a 1951 "See It Now" program, Edward R. Murrow interviews "the Whirlwind electronic computer". After he has Admiral Bolster give the "whirlwind its workout," Murrow says, "Well, I didn't understand the answer, and I didn't even understand the question." This seems really quaint to today's visitor because the whole program that the Admiral wants run on the building full of Whirlwind, is running on a Compaq that was programmed by summer student.

This first exhibit illustrates the revolution, the unbelievable power of the first computers in the early fifties, and their incredible evolution in thirty-five years. The Whirlwind occupied a building, consumed 150 kilowatts and cost as much as $20 million. The equivalent personal computer sits on a desk, plug into a wall socket, and costs two thousand dollars.

The AN/FSQ-7 and SAGE System

The Q7, a production version of Whirlwind, was probably the largest and longest lived computer in existence. It illustrates the computer components that are now on a single board or micro-chip.

The arithmetic and memory units with their 55,000 vacuum tubes took a very large space. The visitor can walk through the seven foot high banks of vacuum tubes and up to the four foot by four foot by eight foot 32-K core memory stack. The equivalent chips are exhibited and a terminal to the VAX provides a tutorial on how core memory works.

The control consoles were so large that they took up an entire room with several operators. The activities of the other components of the machine were shown in flashing lights on the consoles and the operator had a telephone to communicate with the people on the arithmetic, input-output units, or generator for the power.

The "Blue Room" consoles had large round screens that showed aircraft moving across the airspace. The screens were updated every 15 seconds by the Q7 causing a constant irritating flicker, hence a soft blue light in the room for the purpose of seeing the screen. The consoles display the air situation display and some were especially designed for weapons assignment or interception. The exhibit includes the consoles, chairs with their special drawers on the seats, and ceiling panels to recreate the feeling in the "Blue Room".

A console from the SAGE Blue Room, the control room for the SAGE, the U.S. air defense system from 1958-1983. Here, Computer Museum visitors can see the oversized video display terminals that served as the first computer graphics output devices that used light guns to identify the airplanes shown moving across the screen.

SAGE Blue Room.

Visitors walking through two rows of the AN/FSQ-7 arithmetic unit. Each computer had 55,000 vacuum tubes with 300 changed each week for preventive maintenance, whether they needed it or not.

UNIVAC I

After UNIVAC I was featured predicting the Eisenhower election of 1952, the name almost became synonymous with "computer." The video-tape and components of a UNIVAC I bring this era back to life.

J. Presper Eckert, Walter Cronkite and Charles Collingwood with the UNIVAC on election night in 1952. At 8:30 p.m., with only a few million votes tabulated, UNIVAC's first prediction showed a landslide victory for Eisenhower. Since nationwide polls had indicated a close race, Remington Rand officials revised the national trend factor and had UNIVAC recompute. At 9:15 p.m., UNIVAC publicly predicted 8 to 7 odds for Eisenhower. By 10:32 p.m., all predictions showed that Eisenhower would decisively beat Stevenson (442 to 89 electoral votes). The president of Remington Rand went on the air to explain why they had tampered with the original prediction.

Computing from 1950-1969:
A Year by Year Timeline

The first two generations of computing are illustrated in a timeline with artifacts that move the visitor year-by-year over this twenty-year span. The invention of the transistor is at the beginning and the introduction of the NOVA, a third generation integrated circuit computer at the end. Unique artifacts, such as a unit from the EDSAC and the ILLIAC I, are complemented with illustrations of new technologies, applications, and ephermal materials such as "Do not spindle" buttons.

The timeline is meant to be evocative of a walk through history. We hope that it will also bring to light many hitherto buried artifacts for preservation as part of the history of information processing.

Gordon Bell and Mass. Secretary of Commerce Evelyn Murphy looking at the early sixties section of the ."Timeline." A module from the ILLIAC 2 hangs over an Olivetti Programma next to the teletype. Over 100 artifacts are included in this twenty-year timeline.

This picture of the 1969 Data General Nova and three of the company's founders, Edson de Castro, Herbert Richman, and Henry Burkhardt, ends the Timeline.

Batch-Processing in 1965:

An IBM 1401 Computer installed at The Travelers

The 1401 was the largest-selling transistorized computer. Its low price made it one of the machines which stimulated the tremendous rise in the business use of computers during the 1960's.

The exhibit is composed of three sections: the computer room, containing an IBM 1401 system; a card punch department with an operating card punching machine which visitors can use; and a programmers office strewn with vintage programming paraphernalia.

The 1401 was designed in the mid -1950's to consolidate all of the various functions of IBM's electric punched card accounting machines; such as calculation, interpretation, collation and sorting of data. It operated on alphanumeric characters (letters and numbers) and used a variable word length. A unique feature of the 1401 was its add-to- storage feature which sped up calculation rates by eliminating the time taken for reading information from memory. The 1401 was basically intended as a card-based system, however, it was also able to use magnetic secondary memory in the form either disc or tape.

IBM announced the 1401 in 1957 and delivered the first unit in 1958. Over 12,000 were ultimately installed. The success of the 1401 led to a small line of computers: the 1410, the 1440 and the 1460. The 1401 was the second-to-thesmallest of IBM's computers at the time. The scientifically-oriented 1620 was slightly smaller.

The principle use of the 1401 by Travelers was the generation of reports for management from information on policies issued. Information relating to policies, such as the name and address of the issuee, coverage, claims filed, etc. was stored on 80 column punched cards. Reports would be generated from these records according to a program directing which information was to be used and how, and how the result was to be presented. The speed and versatility of the 1401 permitted the condensation and manipulation of vast amounts of information into useable forms. This provided management with information about the trends in policies and claims allowing more informed decision making.

The 1401 was a batch processing machine. Programs and data were fed to the computer one at a time exclusively by an operator. The programmer was isolated from the machine. This made the process of programming very difficult since the programmer rarely got his hands on the machine. Instead, he would encode the program he was writing, submit it to be punched from the code sheets onto 80 column cards, then have the cards delivered to the computer room with a batch of test data. The program would be run in between jobs. If it had a problem the operator would print out the contents of the memory and have them delivered back to the programmer, who would try to find his mistake and then start all over again. If the programmer was good friends with the operator, he might be able to persuade him to let him de-bug his program on the machine late at night or some other time when the machine was not busy Programmers "drove the operators crazy" and operators "drove the programmers crazy." A film in the "See It Then Theatre" entitled "Ellis D. Kruptechev and His Marvellous Timesharing Machine" illustrates batch processing and the change to timesharing.

The IBM 1401 computer room recreated as it would have been in 1964 at an installation in The Travelers Companies. Francis Hjarne and Thomas Ottman of The Travelers provided the period ephemeral material, just as 1964 World's Fair posters and wall calendars to appropriately outfit the room. One of the only criticisms is that we don't have any period crumbled up candy bar wrappers on the floor-if anyone knows the whereabouts please send them to us and we'll add to the decor.

Focus on an Individual: Seymour Cray

> "Seymour Cray is the most outstanding high-performance scientific computer designer in the world."
>
> Gene Amdahl

Thus, it is appropriate that Cray is the first individual that is featured in this exhibit. The intent is to change the exhibition on a yearly basis, selecting people that represent various aspects of information processing: languages, applications, entrepreneurship, and even use.

The 33-year-long career of Seymour Cray illustrates the progress of computing. He has achieved this status through practicing a unique philosophy combining a small and isolated work force, with a simple logic and circuit design. His fame and self-imposed isolation have created an aura of myth around him. The exhibit traces Cray's career by means of a combination of artifacts, photographs, and a video tape of Cray giving a lecture.

Seymour Cray was born in 1927 in Chippewa Falls, Minnesota. The son of a city engineer, Seymour exhibited an interest in science in high school. After graduating in 1943, Cray entered the military where he worked repairing radios. After WW II he went on to earn his Bachelor's degree in electrical engineering at the University of Minnesota in 1950, and a Master's in Applied Mathematics a year later. One of his professors recalls how Cray "had the almost uncanny ability to see through all the possibilities . . . and arrive at the [best] solution."

In 1951, Cray went to work for Engineering Research Associates (ERA), a Saint Paul, Minnesota computer company founded in 1946. He was instrumental in the production of the ERA 1103, which, when it was announced on February 5, 1953, was one of the first commercially-available computer systems. After Remington Rand Company bought ERA, Cray stayed on as a principle designer of the unit computer of the Naval Tactical Data System (NTDS), a weapons control system designed under contract for the Navy. The first NTDS computers, completed in late 1957, were some of the first fully-transistorized computers. Serial number one of the heavily-armoured NTDS computers is on display in the exhibit.

According to Cray, "My story really starts with the beginning of Control Data." In 1958 Cray left Remington Rand Univac to join a group of his former ERA collegues who had formed Control Data Corporation. At Control Data, Cray commenced work on a low-cost, high-speed, powerful computer for scientific computation. To test the soundness of his logic and circuit design, Cray produced the Little Character. This machine, also on exhibit, served as the prototype for Control Data's first product, the 1604 computer system, named to represent its 16 thousand words of memory and 4 tape drives. Cray continued to pursue his inclination toward the design of large and fast systems for the forefront of computing.

On August 22, 1963 Control Data announced the 6600. This computer, designed by Cray James E. Thornton and a handfull of others in a remote laboratory which Cray had built in his home town of Chippewa Falls, was the most powerful computer of its time. It was three times faster than IBM's Stretch computer, yet a fraction of the size and cost. The 6600 exemplified many of Cray's design philosophies. For instance, its relatively small size reflects Cray's tenet that to make a computer fast one must make it compact. Half of a 6600 makes an impressive center-piece to the exhibit. On December 3, 1968 Control Data announced the successor to the 6600. The 7600 was 5 times faster than its predecessor and cost only twice as much. A set of notes on the operation of the 7600 written by Cray is enshrined in a plexiglass case in the exhibit. It encapsulates many of Cray's design philosophies; earning it the nick-name "Seymour's Bible."

Seymour Cray and John Rollwagon, President and Chairman of Cray Research, stand next to a prototype of the CRAY-2. To keep the components cool, the entire CPU will be immersed in inert fluorocarbon, the substance used for artificial blood.

In 1972 Cray left Control Data to form his own company: Cray Research Incorporated. After fours years of work, Cray Research delivered the Cray 1 to the Los Alamos National Laboratories in early March, 1976. Its radical design and $8 million price tag led some to call it "the world's most expensive loveseat." A section of the Cray 1 is on exhibit at the Museum. Above it is a large image of the computer which was generated by a Cray 1 computer, illustrating the use of the large computers for graphics and entertainment applications as well as the large-scale number crunching.

The Computer and The Image

Computers' ability to manipulate and create images has changed radically in the last twenty years. Images take large amounts of memory to store, and correspondingly large amounts of computer time to process. Computer imaging of all kinds has benefitted directly from the steady decline in the cost of computer memory and processor cycles. Still most uses of computer graphics and image processing are confined to the workplace and research laboratory For example, the animation possible on a personal computer is based on stick figures, in contrast to the 1984 two minute "cartoon" with three-dimensional figures made by Lucasfilm with the help of a Cray XMP and ten VAXes.

The image gallery both reflects the history of this application and provides a glimpse into the future. Many of the fruits of computer imaging are easily comprehended, yet are rarely seen in public. Those programs that run off the Museum's mainframes will undoubtedly be available one day on the individual workstation or home computer.

The gallery's frontispiece is a large Landsat mosaic spanning a 300 mile square region of Southern New England and New York. The image relied on digital techniques, both for its capture (there is no camera on Landsat, only an instrument that measures the brightness of one point at a time) and for its enhancement and assembly.

This leads into a section on image processing. Working exhibits allow the visitor to degrade the resolution and number of shades of grey on a digital image of his/her own face and pan around a Landsat picture of eastern Massachusetts showing detail down to a scale of 30 meters.

On display is the first picture of another planet taken from a vantage point in space. The data was sent back by Mariner 4 during its 1965

Mars fly-by. While the data slowly emerged from the printer, the project scientists, eagerly awaiting their first closeup view of Mars, hand color-coded and stapled up the strips of printer paper. The result looks rather like a child's painting, but does reveal some Martian craters.

In the computer graphic technology section, two cases show graphic input and output devices. Rare items include the Rand Tablet and the crystal globe from MIT's "Kludge" terminal-one of the first geometric input devices. A video shows early graphics projects, from Ivan Sutherland's Sketchpad to the General Motors DAC-1, one of the first uses of computers in industrial design.

Associate Director and Curator of The Computer Museum, Dr. Oliver B.R. Strimpel, and Harvard University professor, Dr. Benoit B. Mandelbrot, also an IBM Fellow at the Thomas J. Watson Research Center, are shown standing with "Fractal Planetrise," an artificial computer generated landscape in "The Computer and the Image," a major gallery at The Computer Museum. Fractals are mathematical objects developed by Dr. Mandelbrot and have been used as models of natural phenomena such as,' turbulent fluid flow and the shapes of rivers and coastlines. Fractals have recently played a role in the synthesis of artificial landscapes for the film industry.

Several exhibits use the fine view of downtown Boston from the gallery indow as a starting point: a television camera captures an image for the visitor to color in digitally, a plotter continuously draws differently colored and shaded views, and a video shows both a walk through a 3-dimensional database of the city as well as an exhilarating range of special effects applied to stretch a 2-dimensional version of the view into " 2.5" dimensions.

The techniques of realistic image synthesis are shown in the section, Building an Image. Lighting, subtle color shading, the simulation of texture, transparency, reflections, and refractions of light are all shown. For many years, researchers in computer graphic realism used the data set that graphically reproduced Martin Newell's teapot to test their methods. The original teapot is now on show here in a mini stage set, next to a computer generated rendering of itself, complete with artificial colored lights. Here too you can browse through 3-dimensional computer models of houses on offer by a commercial builder.

A section on computer-aided design lows images and objects designed with the help of a machine. Examples range from parts of a Boeing 757 to an Olympic running shoe. At interactive stations visitors can design a car and complete the design of an electrical circuit. A large high precision pen plotter draws the artwork required to fabricate a microprocessor chip.

Interactive demonstrations allow the visitor to make his/her own fractals and cellular automata. Both are useful models of some natural phenomena, and rely on computer graphics for their investigation. Fractals are useful in generating artificial landscapes, several of which are shown here. In a section entitled Simulation, a video shows examples from the modelling of galaxy collisions to the interaction of a DNA molecule with a drug. The fantasy world of SPACEWAR!, the first computer game written by MIT hackers on the DEC PDP-1 computer in 1962, is demonstrated on special occasions on the PDP-1, and otherwise runs on a modern micro. Visitors can also fly a Cessna using a flight simulation program. A video shows state-of-the-art use of graphics in flight simulation, landscape synthesis, education and advertising.

Perhaps the most appealing use of computer graphics is in the making of films, both for animation and for the creation of convincing fictitious scenes. A computer animation theater shows a series of films from the earliest use of key frame inbetweening to the latest offering from Lucasfilm, completed in August 1984.

The visitor should be able to sense the excitement and challenges of this rapidly changing field in computer applications, as well as absorb many of its fundamental concepts. Much of the film, video material and working demonstrations will be updated to keep abreast of developments.

The Integrated Circuit: Origins and Impacts

by Robert N. Noyce

As I was driving in tonight, I was listening to a Chrysler ad pointing out that the company was 60 years old. I think of Chrysler and the auto industry as old. Then, I thought, the semiconductor business must be reaching middle age, since it is now over 30.

In 1954, the semiconductor business amounted to 25 million dollars, the growth sequence then was 35, 80, 140, 210, 360, and then 550 million by 1960. Half the business was in transistors; silicon accounted for a relatively small share.

In the fifties, everyone was trying to figure out new and better ways of making transistors. At one of the solid state circuits conferences, an explorers kit, designed to keep you from getting lost in the woods, was displayed. It consisted of a box with a small cube of germanium and three pieces of wire. If you got lost, you were to start making a point contact transistor. Whereupon ten people would lean over your shoulder and say "That's not the way to do it." Then, you would turn around and ask, "Where am I?"

At the time, germanium alloy transistors were made by putting indium on top of semiconductor germanium and melting it just enough to dissolve some of the germanium and then recrystalizing it on both sides to make a PNP transistor.

One baffling research question was why germanium, when it was heated and then cooled in the laboratory, changed from N to P type. Simultaneously transistors were being manufactured with N type germanium on the factory because the indium acted as a getter to pick up all the impurities instead of converting the germanium.

In the mid-fifties, the thinnest possible transistor was a fraction of a mil and a mil was a megacycle so these weren't very useful for anything except for hearing aids.

Between '54 and '55, we started worrying about diffusion as a way of getting impurities into the semiconductors, giving good control of the depth dimension. The problem was to get control of the other dimensions. Some of the first work was done at Philco because the semiconductor group worked right across the hall from the laboratory that was working on etching shadow mask tubes for color television. They were experiences' with photo engraving, which turned out to work a lot better.

The invention of the planar transistor by Jean Hoerni further set the stage for the birth of the integrated circuit. Planar transistors solved the problem of impurities on the surface of the transistors and at their junctions that had been lousing up the specified characteristics. Hoerni's idea was to leave the silicon dioxide, a very good insulator, on top of the transistor when it was being diffused, thus forming a protective cover.

The government gave further impetus by their interest in getting things into smaller packages. The Air Force project Tinker Toy and the concept of molecular engineering didn't really work very well, but it did let everyone know that there was an interest in getting things small. A square inch chip with ten thousand transistors was very labor intensive: each transistor had to be attached by a couple of wires and soldered down. There had to be a smarter way.

I remembered that when I was in college, I could slave over something, finally get the right answer, hand in my paper and it would come back with big red markings on it. My physics professor would say I did it the hard way. Then he'd jot down a couple of sentences which clearly made it much easier for me by using some other method. I guess that is what stuck with me because one of the characteristics of an inventor is that he is lazy and doesn't like to do it the hard way. Putting those 20,000 wires on 10,000 chips of silicon seemed like the hard way to me.

Although the printed circuit board was starting to be used, the thought of printing a circuit on top of the transistors had not occurred. It was the genesis of the idea of the integrated circuit. All the elements were converging: photo engraving enabled reproduction and the planar transistor allowed conductors directly on top of it. Three ideas popped up at that time. One was junction isolation, which I patented, even though it turned out that Kurt Lehovic had thought of it years before at Sprague. J. Last at Fairchild thought of the idea to etch the transistors apart, glue them down to something and if you still knew where they were you hopefully put them together. This idea had been previously patented at Bell Labs. The one I did get a patent on used intrinsic isolation, that is to use the silicon as an insulator. It didn't work well at first because by bombarding it with neutrons or doping it, leakage occurred and the life was too short. Junction isolation is now being broadly used.

After the original concept was developed, things moved very slowly. One reason was the low yield on transistors: with 50% yield and ten transistors together, the final yield of one over two to the tenth is a small number. We didn't even consider putting a thousand transistors together. Another problem was that the early integrated circuits were very slow. And, of course, the market was opposed to this innovation.

Progress followed the classic Moore's curve. Every year you could get something twice as complex as the year before. That extrapolates to a million elements in 1980. We didn't quite make that unless you allow for the introduction of new things like magnetic bubbles. The technology also changed from bi-polar to MOS.

Costs are determined by complexity and the number of leads per square inch of silicon with problems setting to 20,000. Starting with a 5/8th inch wafer in 1963, costs were reduced by increasing the size to 1.5 inch in '65 and two inches in 1970. The die size and area were also increased to reduce the density of defects that would kill the surface. It became possible to use an ever increasing area to put a circuit on and have it work. Circuit dimensions themselves have been reduced below the size of neurons, 10 microns, and these are being used for speech synthesizers and other products. Today, we have two micron circuits ands are talking about .7 microns, so we indeed are getting down to biological dimensions and it is conceivable to talk about things the brain can do.

Other new ideas were important. One was MOS and the second was epitaxy. Prior to the use of epitaxy only the surface could be more impure than the underlying material. This was another bag of tricks.

The first set of integrated circuits had straight Boolean functions. With progress the designers wanted complexity with lots of leads out of a circuit and the semiconductor manufacturers just didn't like that at all. In addition, the more complex products had a lower demand, and as manufacturers we were thinking of making millions of items Simultaneously the computer companies in the early seventies were talking about tens of thousands per year. One kind of chip, however, was like heroin to the computer designers and that was memory Give them a little bit and they want more. Thus, memory chips became a major standard product.

What has the chip wrought?

The chip has been one of the main elements allowing the ubiquity of computers. Computers, as tools and devices to help train people to think logically and work precisely, have caused a major revolution in education, business, government, and all aspects of society. The telecommunications manufacturers would have us believe that every telephone in the world will be a computer terminal.

Some people fear this idea, just as I feared the telephone. One day when I was quite young, my folks were out and left me alone. The telephone rang. I panicked, picked it up, and said, "Hello, nobody's home." Then hung it up. Today I can't imagine living without a telephone.

Let me point out a couple of other changes that I've observed. The first computer in an automobile only controlled the non-skid brake and exhaust and it cost twice as much as the car and filled the whole trunk. In fact, the rear seat had to be used as well in order to install the computer. Today computers in cars do ten times more work and cost about $30. They are less expensive than a mechanical carburetor and will pay for itself in the first year in gas savings.

Jobs in the future are not going to require the skills of the past. Onehundred-and-fifty years ago, 50% of the American labor force was employed on the farm. Fifty years ago the greatest proportion was in manufacturing. Today that is about 20%. These latest statistics are inaccurate because the categories have not changed with the economy. Intel is included in the manufacturing sector, even though only 30% of our people actually touch any products that are shipped. Most of our employees sell, keep books, or even do such useful work as design the next generation of products. Today more than 50% of the labor force is working with information.

The computer is the major tool that can help information workers. It's a productivity enhancer for people who work with ideas as well as for people who work with things. It will allow more human use of human beings. Dull repetitive tasks are the first to go. example, retyping a letter for one mistake, or reformatting a marketing forecast.

The tradition of liberal arts education was designed to allow people to understand and communicate in society.

Grammar, rhetoric and logic came first, and then the quantitative studies of arithmetic, music with its geometrical relationships, geometry and astronomy followed. The same task is essential today. The student has new tools to help understand the continuing accelerating advances in technology. Most students will be working with a computer in some way

It's not necessary for society to breakdown into C. P Snow's two cultures in which those who do not work with technology are left behind those who have the modern tools to become productive. Despite the advances in technology, math, science and engineering are not attracting enough people in the US. The power of our computers that can help people as tools is growing beyond common imagination.

The Computer Museum has the CDC 6600, the first production supercomputer from 1963. It cost more than $3 million and only had 500,000 transistors. That will be available on a single chip within a couple of years and everyone can have a supercomputer. All the educational institutions have a challenge to make this work for the science and liberal arts.

The microprocessor or microcomputer was introduced by Intel in 1971.

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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). Top brass from IBM, Harvard, and the US. 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. 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.

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. 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." 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. This difficulty 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. 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. 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. 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."

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 use several trancendental functions such as 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.

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 the principle components which it should 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. 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.

Aiken "visualized [the machine] as a switchboard on which are mounted various pieces of calculating machine apparatus." 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.

Convinced of the viability of building an automatic scientific calculator with existing 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. Furthermore, President

James Bryant Conant of Harvard warned Aiken that he was risking a tenured position if he continued to pursue implausible schemes. 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." Bryce was recep- tive 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.

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. 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. 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.

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. 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.

Wartime Advances

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

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 ??? 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. 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. With astonishing precision, lay people saw many of the longrun 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." 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." 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.

This massive frame held 765,299 separate parts, including over 3,000 relays (electric switches), and 225 circuit breakers, connected by 530 miles of wires! 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.

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.

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

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 inout-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.

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 t know how he knew that. but he did."

Commodore Grace Murray Hopper, speaking at The Computer Museum. April 14.1983.

While addition and subtraction were performed directly in the storage 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. 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. 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.

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. 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 threesection 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 "buss" or large circuit, which' connected all sections of the computer. The third section specified what operation was to be performed upon the numbers. 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. 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. 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.

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. The code book elaborated the basic means of programming almost every type of mathematical problem known.

In sum, the Mark I was a vast electromechanical 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 generalpurpose 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. 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). 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.

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. 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

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. In 1947 and 1949, the Harvard Computation Laboratories sponsored two symposia on "Largescale 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." 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. 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.

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. 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. 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.

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 greatgreat-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. 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.

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.

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.

A 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 goodnatured 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.

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.

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. " 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.

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. 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." 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."

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. 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. 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."

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."

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Highlights from

The Computer Museum Report

Volume 13 ---- Summer 1985

Contents of Highlights

The President's Letter

When I wrote the first letter in the first The Computer Museum Report in May 1982, I was the President, Treasurer, and Executive Director of the Museum. The whole staff consisted of three other people plus some summer students, and there were about 100 members. After a year, the Board of Directors decided that I shouldn't create, write, and sign the checks and Professor James McKenney became Treasurer.

Then this year, the Museum had its first assessment on the way to accreditation by the Association of American Museums. It became equally clear to me that the role of President and Executive Director of an ongoing public museum were indeed different. There was no way for me to do all that I have been doing as Presidentmaintaining a close, ongoing relation with the computer industry-and also be a director of this major museum that is making a significant footprint in the Museum community.

It is with great pleasure that I introduce Michael Templeton as the new Executive Director. Michael was actually the first museum professional to visit the museum! In the fall of 1980, when he was the Executive Director of the Association of Science and Technology

Centers, ASTC, he scheduled a meeting at the Museum in Marlboro of their advisory board for the travelling exhibit, Chips and Changes. At the time, he encouraged me to push ahead and develop the Museum.

My next visit with Michael was in Portland, Oregon, where he had become the Director of OMSI, the Oregon Museum of Science and Industry a Museum that I had long admired. Why? First, Oregon Software originated there. This company was formed by a group of students and their physics teacher, Rusty Whitney, who wrote a Pascal compiler on the PDP-11 in the basement of OMSI. Ten years later the company is alive and thriving. Second, OMSI pioneered in computer- based exhibits and had a very good working relationship with the electronics firms in the Northwest.

At the time of the Museum assessment, I thought that one of the few people in the world who could come in and be in synch with the Museum was Michael Templeton. When I called his home in Portland, I learned that he was consulting at the National Science Foundation. He changed his plans and travelled back to Portland via Boston, walking into the middle of an exhibit planning meeting. Everyone felt that this was a match that was meant to be. I will stay on as President and CEO (in the jargon of industry) and he will be the Executive Director and COO.

The New Trustees

Each year, a class of the Board of Directors retires to become Trustees of the Museum. This year, Gordon Bell, Harvey Cragon, Robert Everett, George Michael, Ken Olsen, Kitty Selfridge, and Erwin Tomash made this step. Gordon Bell and Bob Everett will continue to work on the development committee to ensure that the capital campaign will reach its goal by 1988. Harvey Cragon, George Michael and Edwin Tomash will remain involved with the Collection and Exhibition Committee. Kitty Selfridge, who started the member volunteer organization, will remain an active member of the Museum. And finally, Ken Olsen, who was the first Chairman of the Board, will remain a vital force behind the scenes.

The New Board Members

Seven people were elected to the Board of Directors, each bringing special talents and perspectives to the table.

Sir Arthur Humphreys, retired Chairman of ICL Ltd., renews the Museum's connection with The Charles Babbage Institute, of which he is a trustee, and strengthens our international ties.

August Klein, President of MASSCOMP has come on board as the Chairman of the Museum's capital campaign. In Gus's words, "I don't just join an organization, I invest in it." His experience comes from both business and philanthropy: he was a 25 year employee of IBM and served as a director of United Way in Greenwich, Connecticut, Denver, Colorado, and Jacksonville, Florida. Gus is establishing a committee to meet our March, 1988, deadline of $10,000,000. He also says, "Hey, I'm delighted to start with one-third of the goal in our pocket."

Robert Lucky Executive Director of the Research, Communications Sciences Division at AT&T, is a Fellow of the IEEE, a member of the National Academy of Engineering, and a member of the Advisory Committee of the National Science Foundation. He will help the Museum develop its collections, exhibitions, and publications on the subject of communications and computers.

Carver Mead, Gordon and Betty Moore Professor of Computer Science at Cal Tech, views the microprocessor as computer. He is spearheading our efforts to "get the semiconductor story right." This leads the Museum in the direction of collecting and exhibiting the evolution of chips and how they are made.

William Millard, Chairman of ComputerLand, was part of the firm that developed the groundbreaking IMSAI-8080 microcomputer. Watching the early growth of the IMSAI dealer network, Bill Millard established ComputerLand in 1976, a franchise network that provided financial and business experience to computer retailers. He is personally interested in both history and the future. Reflecting these interests, he has established a ComputerLand competition for the earliest microcomputer artifacts donated to the Museum. He will also spearhead a long range planning committee for the Museum.

Jonathan Rotenberg is President and Founder of the Boston Computer Society, the largest one of its kind in the United States. His longtime dream has been to establish a computer discovery center-an idea that extends the museum exhibit plans. He will work with us to build the computer discovery center into the Museum.

Maurice Wilkes built the first, operational, full-scale stored program computer, the EDSAC, and gave the very first Computer Museum Lecture, making him a bona fide pioneer not only in computers but in the establishment of this Museum. Maurice, a senior engineer at Digital Equipment Corporation, is extraordinarily interested in the preservation of both the software and hardware that laid the foundations for the industry. Parts of the EDSAC, languishing in the basement of the Science Museum in London, were sent to us for exhibiting. His contributions will help us develop historical exhibitions planned for next year.

The new Board members have a diversity that reflects that of the Museum. Our exhibits contrast state of art with historic firsts, include the stories of individuals and corporations, and encompass all the levels of integration from silicon to software.

The future of the Museum will continue to evolve. The new executive director and new class of directors renew our activities. Personally, my role will again change as the Museum becomes broader and deeper. And I'll be around and willing to do what is needed to make the Museum great.

Gwen Bell
President

Computer Animation in the Museum

by Oliver Strimpel

Film and video animated by computer are an important record of hardware and software development. The need to produce large numbers of images and to animate them smoothly absorbs a large amount of computer time and fully exploits all the available spatial and color resolution of computer graphic systems. Makers of film and video have consistently stretched their resources to the limit.

The Museum is building up a collection of computer-animated film and video. An important recent acquisition is a set 12 films donated by Ken Knowlton made at AT&T Bell Laboratories between 1963 and 1976. The computer (an IBM 7094) was used both to draft the images on a microfilm recorder (a Stromberg-Carlson 4020), as well as to calculate what should be drawn. A short piece by Ed Zajac that simulates the oscillations of a communications satellite in the Earth's gravitational field was completed in 1963, making it the earliest computer generated film known to the Museum. Several of the films are educational, visually explaining subjects such as Bell Labs' own movie-making system, programming languages, and Newton's laws of motion and gravitation. Others explore human visual perception using images with random noise, and still others use the medium for its aesthetic possibilities.

Another significant set of computeranimated films were donated by F R A Hopgood. He led a group who used the Atlas computer at the Rutherford Laboratory in England to develop a convenient high-level computer animation system from 1968 to 1973. The Museum's films explain concepts in computing and physics, but non-technical entertaining films were also made. The system A later developed into a package called ANTICS which continues to be used today, particularly in Japan.

Also in the collection is a record of the first real time animation, a simulated flight of the Apollo LEM. This was filmed from the screen of an Adage Graphics Terminal in 1967.

The Museum has created a minitheater in "The Computer and the Image" gallery to screen some of the more recent pieces in the computer animation collection for the public. Five pieces spanning the development of the art were selected for a 20 minute program which shows continuously. Each piece demonstrates creative and original use of the techniques of computer animation.

Computer key frame inbetweening is the process whereby the artist only draws the frames that represent the end of a movement or the completion of a metamorphosis. The computer automatically computes and draws the intermediate frames.

Here, the artist drew the first and last pictures of the series using a tablet connected to a computer, and the machine generated the frames in between. When seen as moving film, the metamorphosis appears continuous.

The Story of the COBOL Tombstone

The following is a transcript of COBOL's 25th Anniversary Celebration at The Computer Museum on May 16, 1985.

John L. Jones, Chairman of the CODASYL Committee: The fact is that no one has ever admitted any involvement in the Tombstone. Furthermore, no one has ever explained the meaning, intent, and thought behind the Tombstone.

Let me explain that COBOL and the CODASYL Committee are alive and well and have never had to make use of this tombstone. Both are strictly voluntary committees; in fact all of the work is done by volunteers and always has been done that way. We work on actual language development, refinement and clarification.

One of the key concepts of COBOL was Flowmatic, an idea that was developed by Commodore Grace Hopper. Flowmatic had one other derivative from an Air Force Project, the Air Material Command Compiler, "AIMACO," that was, as far as I'm aware, the first effort to take one language and apply it to efforts on two very different machines, the IBM 705 and the UNIVAC 1105. The compiler ran on the UNIVAC 1 and developed programs for the binary 1105 and the decimal 705. That was another inspiration to begin COBOL.

In 1953-54, most people wanted to program in machine language. The idea of compilers, like the first idea of power steering in automobiles, was intensely resisted: you lost the "feel" of the machine just as you might loose the "feel" of the road. I worked quite a bit with Grace at that time, talking about a compiler "AO" that she had written. In my 1954 Master's thesis I quoted her about using networks of small computers to perform functions that at that time were limited to big computers. Then, this quote about what we now call "distributed processing and micros" was used in the IBM anti-trust case around 1980.

Grace Hopper: When I started, I just went ahead with the idea. I have later learned that it is much easier to apologize than to get permission. In the case of Flowmatic, we discovered that a lot of people hated symbols, even though the mathematicians and engineers loved them. These people used words. We proposed that we should write programs in English statements providing a compiler that would translate to machine code. I was told that this couldn't happen because computers don't understand words. I said that they didn't have to; they just had to compare bit patterns. "Add" has just as many bit patterns as a plus sign does. But I was getting nowhere. So we acted on the motto: Just go ahead and do it. The lesson that we learned from COBOL is that you must go ahead and do it and make it work, and then get out and sell it.

Donald Nelson, Chairman of the COBOL Committee: The size of specifications of COBOL has grown from a stack of pages three-quarters of an inch high to a stack four inches in thickness. About 60 percent of the programs that exist are written in COBOL, and on mainframes its about 70 percent. The language has evolved over the years to meet many of the criticisms about it. Suggestions and revisions can be made by any group and are then reviewed by the committee.

Jack Jones: Howard Bromberg was very involved in COBOL from the beginning. The first demonstration that Grace's COBOL compiler worked on different machines was done on a UNIVAC 1 and then Howard's on an RCA 501.

We are missing Charlie Phillips, who recognized the idea of COBOL when he was in the Defense Department, and put his energy behind it to make it happen. In 1959, his efforts made COBOL come to life. His untimely recent death was very unfortunate and we sincerely miss him on this occasion that he was looking forward to.

Howard Bromberg: I thought a long time about the Tombstone and whether tonight was the appropriate forum to come clean. Let me set the background.

During the formative days, the COBOL activities represented the primary computer manufacturers of the time. A handful-8 manufacturers and a double handful of computer users were represented. At that time we were attempting to create a specification for a language that would be understandable by users, translatable by machines and easy to learn. We were also concerned that the language would be acceptable on all computers, even though there weren't that many back then.

Having worked with Grace Hopper, I subsequently worked for RCA carrying her banner and using the techniques that she taught me. I was the corporate representative to the COBOL committee and the manager of the Automatic Programming Group. This group at RC was creating an embodiment of the COBOL language specifications in our hardware. We kept about one week behind the COBOL language committee. When we moved a week ahead of the committee, I got nervous. RCA wanted to commercialize COBOL as a product, to have a marketing edge. The other manufacturers were seeking the same goal. As a result we sometimes became testy with one another, and with the organization running the activity. The Committee would meet every six weeks, with each member having very specific technical assignments. The meetings would last three to four days and then we would return to our companies to scheme and work.

One Friday afternoon about 3 o'clock I had an opportunity to discuss my frustration with the chairman of the CODASYL committee, Charlie Phillips. He was the coordinator of everything, good and bad. As such, he was the recipient of a lot of verbal abuse and, later on, a lot of praise. I discussed with Charlie the speed of specification of COBOL. After I described, in colorful **-** language, how I felt and the problem that this was causing me and my company, suggesting that he do something "with it," I hung up and left work in a fit of pique.

As I drove down the freeway, I saw, to my surprise, a monument company next to an exit. Easy off. Easy on. So I did the easy off.

I went in and said, "I'd like to buy a monument."

The salesman said, "You've come to the right place. What did you have in mind?"

"A serious monument that would show my appropriate respect. Since I have to send it, I would like it to be compact." He stepped back and let me wander around. I chose that tombstone because I liked the sacrificed lamb effect.

Mind you, when you buy a monument, it is blank. So the clerk asked, "And what name do you want inscribed?"

I said, "I'll write it for you." I wrote the name down: COBOL.

"What kind of name is that?" **-** "Well it's a Polish name. We short ened it and got rid of a lot of unnecessary notation."

"Fine. Give me the money and come back in two weeks."

In two weeks I returned, still in a fit of pique, mind you. To my surprise, he had gold leafed the name. Today is the first day that I have seen it in twenty-five years and I am still very pleased. Back then, I took it home, not to my office, which is probably the smartest thing that I've ever done. My neighbors helped me build a crate for it out on the sidewalk because they wanted to get the thing out of the neighborhood. I put my name and home address on it and sent it to Charlie Phillips at the Pentagon and felt better.

Grace wanted me to remind you that I sent it collect.

Now, I have denied this story for years. People would call up and ask me, "Hey, did you send that tombstone?" And I would always respond, "What tombstone?" It appeared in a drawing on the cover of the ACM Communicatons. More phone calls. I would say, "I don't know anything about it." Grace in her travels used to tell the anecdote. And even more phone calls. But still denial, until tonight.

Back to that time. Two weeks thereafter I had still not heard from Charlie. The fit of pique returned. And I said, "He's doing this to me on purpose." So I called him. We chatted about the weather and other nice things. And I thought, he's got me. Finally I said, "By the way, did you receive something in the mail?"

-- Charlie Phillips said, "I did indeed. Wonder what you meant by that?"

I said, "Thank you, Charlie." And I hung up.

I was then called to the Vice Presidential suite of RCA where I worked. The suite was interesting because all of the doors were eight feet tall and the ceilings of the room were twelve feet. I always thought that it was to make the vice presidents feel important and it made me feel very unimportant. After waiting the requisite amount of time, I was ushered into the boss's office. He said, "People at the headquarters in Rockefeller Center have heard that you sent a tombstone to somebody at the Department of Defense. They think this may hamper our ability to bid successfully on defense contracts. Did you do that?"

I said, "Yes."

He said, "Would you like to explain to me why?"

How are you going to explain this to a marketing vice president? So I said, "No."

He said, "Thank you." I went back to my office and sort of organized things, just in case. To their great credit I never heard a word about it again. That also helped my denial to this time. It's here. I did it and I'm glad.

I wondered on the flight out here, whether it really means anything-this hunk of marble. Why are we all here? I guess that it means different things to different people. From my standpoint it shows me the humor that we are able to associate with the work that we were and are doing .... the ability to make fun of oneself personally and professionally makes us noble.

COBOL was so different. There were no individuals; they were sublimated to the group. The accomplishment was incredible because we flew in the face of tradition not knowing any better. COBOL "created" a standard.

Standards are usually not created; they are recognized and they evolve. In the next twenty- five years I believe that we will continue to profit from the lesson we learned from COBOL: that a language has to help people talk to people. People do not talk to machines. This is the whole assumption on which COBOL has been built.

Howard Bromberg and Commodore Grace Hopper share a gleeful moment by the infamous COBOL Tombstone. (Photo: Lilian Kemp)

Participants in COBOL's 25th Anniversary Celebration at The Computer Museum on May 16, 1985, surround the COBOL Tombstone. Left to right: Ron Hamm, current CODASYL Committee Chairman John L. Jones, Dr. Jan Prokop, Oliver Smoot, CODASYL Secretary Thomas Rice, current COBOL Committee Chairman Donald Nelson, Commodore Grace M. Hopper, Michael O'Connell and Howard Bromberg. Also present were Connie Phillips and Nan Wilson, the daughters of Charles A. Phillips. (Photo: Lilian Kemp)

Recollections of Memories from RCA in the Fifties

by Jan Hajchman

The following is a transcript of]an Rajchman's talk at The Computer Museum on March 7, 1985, on The Computer Museum Program Series. Mr. Rajchman is the retired Vice President of Research Information Sciences at RCA.

Maurice Wilkes (builder of Cambridge University's EDSAC): I first heard Jan Rajchman lecture at a course at the Moore School in Philadephia in the summer of 1946. He spoke about the selectron, which was a vacuum tube for storing information, and I admired his ingenuity at the time. Some may think that the pin limitation began with semiconductors, but I can assure you that it started with vacuum tubes.

In the early fifties, I visited Jan at the RCA Laboratories in Princeton where he was working on core memories. I can remember him asking me if I thought that programmers would ever want as much memory as 10,000 words. There was a view then, held by von Neumann, among others, that you didn't need much core memory provided that you had a magnetic drum to back it up.

At that time as today Jan carried out pioneering work on memory technology and it is with pleasure that I am introducing him tonight.

Jan Rajchman: In 1939, a US. Army Colonel visited RCA and spoke of the German superiority in the air and the lack of controllers for US. anti-aircraft guns. The mechanical directors for the guns, which had been designed for use on ships and tanks, were utterly too slow for aircraft. The Colonel said, "I don't know anything about electronics except that it's fast, so why don't you look at the problem." The job was assigned to me.

My natural inclination was to look at how the problem was solved mechanically and to do it electronically the same wag After a few months, I discovered that doing anything analog at high speed was very difficult. Very soon I switched to the digital approach with a binary base and the laboratory developed various arithmetical units including shift registers, adders, multipliers, and an arbitrary function generator, now called a read only memory. It also became evident that the digital technique with many tubes would be very bulky and it would take a long time to develop an anti-aircraft fire control device. At that time, the printing of ballistic tables fell behind the invention of new gun types needing new tables. The idea of one central machine for generating ballistic tables was the origin of what became the ENIAC.

There was some question as to whether the ENIAC could be built at RCA, where we had already done more work, or at the Moore School of the University of Pennsylvania. Frankly, RCA had cold feet. The RCA hierarchy felt that any machine with 30-40,000 tubes would be a monster and would never work. In effect, RCA turned down the job of building the ENIAC. However, we were asked to cooperate, and I went to consult many times. They adapted the read only memory and a decimal rate counter.

While the ENIAC was first tested to make ballistic tables, it quickly became apparent that other problems had higher priority, including some for the atomic bomb. A major issue was how to change the design of the machine from one problem to another. The original ENIAC was designed for a specific problem and then patch cords allowed it to be set up for a different problem. Then people said, "Well, why not relays instead of patch cords?" And from that they said, "Well, why not vacuum tubes? There are vacuum tubes everywhere else." Very, very slowly the idea for the stored program evolved. That is to say, the idea that you could build a machine for any problem without having to know the problem in advance. You could program the machine later to solve the problem. The evolution of this idea took a surprisingly long time. What was missing, of course, was the memory. Obviously the stored program computer has to have a memory for the program and the data.

One of the first ideas (due to Pres Eckert, I believe) was to use a delay line where pulses at one end are detected at the other end, and then are put back at the input. Of course, the more memory there is, the longer one has to wait for any desired bit. It was clear that a "random access" was desirable to avoid this dilemma. The term "random access" was born and I was very unhappy about it. There is nothing "random" about random access memory, because, in fact, the exact address is selected deterministically. I also didn't like the word memory. Memory in animals is more than storage. I like the way the British put it, an addressable store of information. But the term random access memory stuck.

After the war, von Neumann, who was the great proponent of the stored program computer, undertook to build a machine at The Institute for Advanced Study, and asked RCA Laboratories to provide the random access memory on which it was to be based. That task was assigned to me. In those days, with the triumph of the cathode ray tube in television and oscilloscopes, it was natural to think of using it for a random access memory Charge is simply deposited on the screen by directing the beam to the selected address where it remains until again bombarded by the beam. Addressing involved analog deflection and storage depended on good insulation of the screen. Many groups (notably MIT) attempted to realize memories in this manner. Most found that structuring the target was necessary. Professor F C. Williams at Manchester University succeeded in avoiding any such structuring by using a metallization on the outside of an ordinary cathode ray tube and an ingenious use of the naturally occuring redistribution of secondary electrons near the bombarded area. His scheme was a very inventive tour de force and provided early memories using commercially available tubes. However, the signals were very weak and the system of analog deflection very delicate. Extreme electromagnetic as well as mechanical insulation was necessary to protect the machine from vibrations such as those due to a passing truck. (By the way F C. Williams' ideas were subsequent to those of the Selectron Tube.)

Figure 1. An early RCA cathode ray tube that could have been used for storage.

{Illegible diagrams}

Figure 6. A 256 digit selectron tube from the]ohnniac at Rand. Gift of Keith Uncapher and Tom Ellis.

Our approach, the Selectron Tube, was a radical departure from all the cathode ray tube attempts of the time. It utilized a purely digital selection system based on a uniform electron bombardment of "windows" created by two orthogonal sets of parallel bars. By applying appropriate voltages to the bars, the passage of electrons was stopped in all windows except a selected one. The onerous number of individual connections to each bar and its individual drive were avoided by connecting the bars inside of the tube into groups and making connections and drives only for the much smaller number of resulting groups. Such a reduction of addressing channels is possible since the passage of electrons between two bars depends on the potential of each bar. Both need to be relatively positive and equal to each other for the electrons to pass. Hence there is an "AND" gate. By appropriate connections between the bars, a row of bars, or a "picket-fence"; controls N spaces by means of only 2 N at right angles to each other, e.g., an array of 1024 x 1024, or more than a million, could be controlled by only 20 channels. The principle of selection is illustrated by figures 2- 5.

Moreover, the Selectron, in contrast to other memory tubes attempted at the time, used a radically different method for storage. It utilized discrete metal elements that were forcefully maintained at one or another of two stable potentials by a constant electron bombardment. Hence storage of information was not dependent on insulation and did not need any explicit refresh, as in other approaches. The overall electron bombardment of the matrix of bars was not stopped by the bars in the storing condition, thereby providing the "locking-in" current for every element. Only momentarily, during the selection, was that locking current interrupted. Read-out was obtained by using a part of the bombarding current of the element passing through a hole in the element, illustrated in figures 4 and 5.

The particular selectron tube design brought to practical realization had only 256 bits of storage, had a cycle time of 20 microseconds (very short in those days), and required rather extensive power-consuming circuits. (Plans made earlier for larger capacity tubes were not carried out, mostly due to the advent of core memory.)

The Selectron can be viewed as "integrated vacuum technology." We thought of applying such a technology to binary adders and multipliers. These tubes were based on the concept of many internal electrically floating electrodes. Some research was funded by the government and several tubes were partially built. However, the general concept did not seem practical because it required an exact logic predesign that did not tolerate the changes and additions that are inevitable in real life. Incidentally, the early integration of transistor semi-conductor circuits suffered from the same rigidity of design.

During the development of the Selectron, I conceived what came to be known later as the core memory. About a year after we had started to work on it, we heard that at MIT Jay Forrester had independently had the same concept. MIT was working on it for the SAGE project. From that time on we helped each other with frequent mutual visits.

Figure 7. The monster circuitry and power supplies needed to drive the selectron memory at RCA. This machine is similar to the] ohnniac built at Rand.

The idea of the core memory is very simple. A core is made of a material that has a square hysteresis loop. When magnetized by a current pulse, it will assume one or the other of its two magnetizations, and thereby "remembers" in which direction it was magnetized. This "memory" property is a free gift of nature. The main artifice that had to be devised was the magnetization of one core among many in an array in a desired direction, without disturbing the sate of any other core. This is achieved by the coincidence of two currents, one along rows and the other along columns, whose combined effect magnetizes the core at the intersection. The currents are too weak to singly change the magnetization of a core as their magnetomotive force is below the "knee" of the hysteresis loop. Of course the critical need is for a material with a square loop. Actually I had thought of the concept long before; in fact, I cannot remember when it was not evident to me. However I did not know of any material with a "square loop."

To my great amazement one day, I was reading a technical journal and I found that the Germans had developed a square loop material that was used in magnetic amplifiers for submarines. ARMCO Corporation in Philadelphia acquired the patent rights and were manufacturing the material, which consisted of a very thin ribbon of permalloy. This very delicate ribbon was "wrapped" around a ceramic bobbin. Each such bobbin could serve as an element of the core memory MIT had also discovered the ARMCO bobbins and we both used them in early experiments. They were about $10 each, relatively bulky and delicate. It seemed evident that ferrites would be preferable. Ferrites are made of metal oxides, are insulators, produce no eddy currents, and were and are widely used for high frequency transformers and television yokes. In these applications, any hysteresis produces great losses and is carefully avoided. I approached experts on ferrites at RCA and asked them whether the hysteresis they so carefully avoided could instead be greatly accentuated and I was very surprised that in less than six months they produced excellent square hysteresis materials. We immediately proceded to model tiny cores from those materials. Incidental MIT approached other material experts and also obtained good materials at approximately the same time.

Figure 10. Detail of an early RCA memory. Note the use of decimal numbers, chosen because of the craze for decimal machines prelevant at the time.

As is well known, the core memory became the standard and was a key in the development of computers. It was surprising that the memory, which by its very operation requires many elements, should be made by discrete elements assembled into arrays. Why not an "integrated" fabrication of some sort whereby all magnetic elements and their linking conductors are made by some overall integrated technique that made the whole array at once. Thus, from the very beginning there was an issue of "integration" versus "automation" (as cores became gradually made by automated presses, were tested automatically and assembled semiautomatically). For example, RCA and Bell Labs made ferrite plates with an array of holes, each threaded by metalized coatings on the plates. Many groups worked on plated wires, which could be made by a continuous process. However, the cores continued to be made by improved methods and, by and large, provided better operation at lower cost, and thus prevailed against all other magnetic memory approaches. In a sense, automation won against integration.

All the efforts at integration were not lost, however. In experimenting with apertured ferrite plates, we invented the transfluxor, a core with two holes, i.e. a relay with no moving parts. The transfluxor was used in some of the early satellites and for foolproof controls in the New York subway. Ironically, the Russians read our papers and used these devices in many industrial controls as they were very slow in developing transistors. Such magnetic logic circuits might be the basis of computers (in fact Univac had a design) if the transistor had not been invented.

A brief mention should be made of our early attempts at integration on a grand scale: planes with half a million bits. These utilized the cryotron, a superconductive switch invented by Dudley Buck at MIT, and made by thin film evaporation techniques. Interestingly enough, our main problems turned out not to be with the indispensable operation at liquid helium temperature, but rather with the problems of imperfections that seem inevitable with such large and dense arrays. It is these imperfection problems that plague present day large capacity chips, and that are being solved by sophisticated error correcting methods and extreme care in fabrication.

The modern development of integrated circuits is of course one of the present day wonders. Memory chips with a million or more bits are being manufactured at very low cost. The integrated circuit memory chips have given us a solution to the memory that is better by orders of magnitude than any previous technology. In fact, it is very difficult to imagine a better technology. The chip is a triumph of fabrication of geometries at the micron, and soon submicron, scale. Operation is obtained by deliberate geometrical shaping and deliberate synthesis of materials, and is all human artifact, not based on some fortuitous natural property, as that of the square hysteresis of some magnetic material.

In the early days, when any workable random access memory was a great achievement, von Neumann thought that a forty thousand bit capacity would be sufficient, provided there was a sufficiently large serial mechanical memory to back it, i.e., tape, drums and later discs. I was always convinced that there is essentially no limit to the need for capacity in the random access memory, and thought that there was no fundamental need for a hierarchy of memories but merely a practical recognition that such hierarchies provide indispensable storage capacity. Today, large capacity chips provide enough memory so that some personal computer systems need nothing additional (HP). This trend will continue into larger computers, particularly when non-volatile techniques are further developed. In the meantime, greater capacity in random access memories are being sought for image storage and manipulation, as well as for many, if not most, tasks sought by artificial intelligence. I believe that semi-conductor technology will provide ever greater, capacities for these uses. Though nature stores in DNA at densities orders of magnitude greater no reasonable proposal has yet been made to exploit such molecular storage for a random access memory or even for a memory that is accessed in some more sophisticated way, such as through the stored contents. Most inventions of men are imaginative intellectual constructs that more often try to defy nature rather than to imitate it.

Figure 11. Cores held on a strand of human hair.

Honeywell Animals Find a New Habitat

Six of the famous computer component animals built by Honeywell are on display at the Museum. These six of the more than 100 animals made were "rounded up" by Morris Dettman, who sponsored these sculptures for a Honeywell advertising campaign that ran from 1964 to 1978. Honeywell put together the display of the animals along with an introductory case with illustrations of the ad campaign.

Each animal sculpture was produced from the contemporary computer components of the time. Since about half a dozen sculptors from the Boston area were used, several different types were produced. For the most part, the animals are either sculpted from styrofoam or formed from wire mesh and then the components put on the surface to form an appropriate mosiac.

The Story of the Animals

The first sculpture was a fairly primitive, pterodactyl-looking bird escaping from a cage. The headline proclaimed, "You're free. Honeywell's 'Liberator' lets you switch to the H-200 without reprogramming."

The second sculpture was a racehorse. The headline was: "The Honeywell 200 is off and running."

The dragon on display at the Museum was used with the slogan, "Honeywell's new computers introduce a little magic to banking." Walking around the case, the visitor can see how the components are attached to the wire mesh frame.

After use within the ads, the popular animals were often given as awards to employees and customers. We have heard that the pride of lions lie in rest in Phoenix and a six-foot span eagle is in Washington, D.C. The Museum would like to play Noah and at least compile a listing-one by one-of the locations of the animals with a guarantee that we would take any in and preserve them for posterity

The fish.

The fox has a styrofoam base and can be identified as one of the later sculptures because of the use of integrated circuits for the legs.

Not all animals were done in the round since the purpose was photography for ads. Morry said, "The $1,500 to $5,000 price tags on any of the animals was quite cheap when you think of fees for models' time, props and so forth."

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The President's Letter

> "Museums in the modern world exist, we are told, to fulfill a fourfold function: to collect, conserve, exhibit and elucidate. There is rarely any mention of the balance between them, and the stress is always on the first, irrespective of whether the other three can be fulfilled in terms of resouces. Collect or die .... What we should be doing instead is assessing our collections, refining some (dare 1 mention disposal, embodied in that emotive word 'de-accessioning'?), closing others, and, even more important, putting what we have got into good order."
>
> Sir Roy Strong
> Director, Victoria & Albert Museum
> The Listener 25 July 1985

Collecting was the original goal of the Museum, and is our sine qua non. But as our collections increase, selection, conservation, and elucidation become more and more important. This issue of the Report lists the artifacts acquired in the last year and provides a time to assess our holdings.

The table on page 2 enumerates the Museum's computer-era artifact and film collections characterized by the levels of integration from the manufacturing base through applications and even including ephemera. The heart of the collection is in the middle: computer subassemblies and computers themselves. Subassemblies are the largest single collection of artifacts because they include transducer systems, secondary memories, and other major components. The 106 computers are all different, second or third copies of the same machine are not counted here. Why not stop here? Components are often the only remnants of early machines or are sufficient to show a given technology, such as the Atlas "toothbrush memory" or the Intel 4004 microprocessor. Since the goal of the museum is to document all aspects of computer technology, which includes manufacture. The process of how things are made are best recorded on film, hence this becomes a critical form of collecting.

Software, applications, and ephemera overlay the hardware technology levels. The way that software artifacts are counted here is highly misleading: the three items are all historical artifacts, such as Bill Gates' original paper tape of the BASIC assembler for the Altair. Operating systems and software in use have not been entered into "the collection." On their retirement from active use, a judgment will be made as to whether they should be placed in the permanent collections. The largest collection of software that we have is in the form of written documentation, such as the original handwritten Brooker Morris Compiler-compiler. Much of the paper documentation has been accepted, categorized by the box-load and set aside. However, we are sufficiently familiar with the material to find the sets of cartons that researchers need; we have recently supplied lawyers with documents required for several different cases of litigation. The material has not been properly sorted or cataloged and this is on the Museum's agenda. Our collection of applications also appears small, because these are often in the form of documents. The development of the Image Gallery led to the rapid expansion of materials that use computer graphics. Examples include early computer-generated pictures, film and objects designed or manufactured using computers.

Ephemera are intriguing and can be especially important to museums. Old buttons, t-shirts, coffee cups, posters, promotional material, video-tape spoofs, commercials and other objects recreate the spirit of the past as well as the technology. Professor Brian Randell, Chairman of the Museum's Exhibits and Collections Committee, recently wrote to us saying, "I can't stress the importance of collecting ephemera enough. When I was preparing a lecture on computing in the sixties, the advertisements triggered more memories about the era than did the technical articles." Without ephemera the 1950-69 timeline case would be less lively, and the IBM 1401 room would not have any semblance to reality. If anyone has a button collection (and some one out there must have one), we would love to have the

".... .... Memorial Collection of Computer Buttons," or any other special collection or individual items.

This year, the Museum is undertaking a special search for artifacts relating to the history of personal computers. Computerland's President Bill Millard clearly saw that the Museum needed a more comprehensive collection of early personal computers and the materials that went with them in order to create a better exhibit. He convinced Pat McGovern of ComputerWorld to run a series of advertisements publicising our collecting effort and encouraging donations of early personal computing artifacts. As an extra inducement, donors of the "best" finds will be brought to the Museum for the grand opening party of the new personal computer exhibit. The Curator, Oliver Strimpel will be accepting nominees for acquisition until April 1, 1986. Judging will be based on when and where the machine or software was developed, completeness of the artifact, uniqueness, and importance to the history of personal computing.

In this way, the Museum hopes to add many objects to the permanent collection to provide primary source material for history. Even though the book shelves are beginning to groan under the weight of published accounts of personal computing, none begin to be comprehensive, and many are inaccurate. I recently talked to an author who was trying to describe the early days of using the model 33 teletypes with their paper tape readers. He described them as being "kludges" because he had heard they didn't work very well. I asked, "Have you ever seen one working?" He had not even seen one working or not-or talked to anyone who had used one.

The Museum is also trying to establish an international collection and an international view of the history of computing. The article by Dr. Koji Kobayashi of NEC describes his personal involvement in computing in Japan and their early machines. He is regretful when he remembers that the NEAC 2201, NEC's first transistorized computer was junked! And we are both pleased that he is sending the NEAC 2203, a 1958 machine, to The Computer Museum.

This issue of the Report is made possible by all of the people who have donated all of these artifacts to the collection. We all wish to thank them for entrusting their "memories" to us.

Gwen Bell

PS. I wanted to update everyone on the museum's 1985 Attic Sale. On September 22nd, a number of companies, individuals, and volunteers joined museum staff in an old-fashioned attic sale of surplus and donated items, museum store merchandise, and retired photomurals from old exhibits that generated more than $2000 to support the museum. Collecting museums approach attic sales the way porcupines make love-very gingerly-to be sure that no one confuses a museum selling donations or duplicate items unsuited for its collections with deaccessioning-the formal process of separating a collected artifact from a museum collection. In our case, the Attic Sale has benefitted donors, buyers, and the museum itself. We're planning to do it again next year, and are looking for both volunteers to make it a great event and for donations for resale. Just give me a call.

The Evolution of "C & C"
A Japanese Aspect

The United States and Japan have both been involved in the progress of telephony and computing from the very beginning. Now, the advances are spreading throughout the world and can lead to a new era in mutual understanding.

Dr. Koji Kobayashi

In 1876, two Japanese students, Shuji Izawa and Kentaro Kaneko, participated in Bell's experiments with early telephony. Japanese was the second language to be spoken over the telephone set. The very next year, Japan imported two telephone sets that served as a trigger for the establishment of the Ministry of Communications in 1885, and subsequently the nationwide telephone system.

Twenty-three years later in 1899, NEC Corporation was incorporated as a joint venture with what was then the Western Electric Company to implement this telephone system. NEC started by manufacturing telephone sets and switchboards. One of the epoch-making events in the communications technology in the 1930's was the development of the non-loaded cable carrier transmission system. The 1,900 mile system between Japan and China, completed in 1939, was produced entirely with Japanese technology, components and materials. I consider this to have served as the basis of establishing Japan's telecommunications technology.

With the advent of electronics technology, based on the invention of the transistor at AT&T Bell Laboratories, NEC proceeded to manufacture transistors and enter the computer field. In 1959 NEC exhibited the NEAC 2201 computer at the AUTOMATH in Paris. This was one of the first transistorized commercial computers to be publicly operated.

In November 1964 when I became President of NEC, half of NEC's total sales were accounted for by Nippon Telegraph and Telephone (NTT), a semi-public corporation, and other government agencies. Although NTT had several 5 year plans for domestic communications networks, I thought that NEC should not rely only on the demand for domestic communications equipment, but that the company should expand and develop new business. Therefore, NEC went into overseas market. In 1964 total sales were 270 million dollars. In 1984 sales grew 30 times in 20 years to 8 billion dollars. Today, NEC's overseas business amounts to 3 billion dollars or 35% of total sales.

NEC has had business dealings with 144 countries, operating 20 manufacturing companies in 13 countries, 23 plants in 13 countries, and 23 sales and service companies in 13 countries. NEC employs 90, 000 people, 11, 000 outside Japan.

1930's: Desire to Develop Original Technology When I joined NEC in 1929, 90% of the telecommunications patents were owned by foreign countries. Japan's material and component industry was very small with most of the important materials imported from abroad. Young engineers including myself tried hard to find ways to change this. From 1930 a trend emerged that a nation's telecommunications infrastructure should not rely on imported technologies, and that equipment should be supplied based on domestic requirements and proprietary technologies. Thus, developing technology became a goal of Japanese engineers.

Perspective of "C&C"

At that time, Dr. Shigeyoshi Matsumae and Dr. Noboru Shinohara of the Ministry of Communications proposed the first non- loaded cable carrier transmission system in the world. I was selected to participate in this development project to lay 1,900 miles of cable circuits between Japan and China. In 1939, after 7 years of work, the project was completed based on the original technology of Japan. I learned that to accomplish a project, whether it may take 10 years or 20 years, if the team settles down to work and uses their own abilities without relying on a quick fix of borrowing things, the road will open up in due course.

The Forerunner of Japan's Computer Development It is said that Japan's computer industry started about 10 years behind the United States. In 1946 when the world's first electronic calculator, ENIAC, was unveiled at the University of Pennsylvania, Japan was in a period of turmoil. After the conclusion of the peace treaty in 1952, communications led to the reinvigoration of technology. The development of radar during the war brought progress in pulse technology, and led to the development of digital multiplex systems using pulse-time and pulse-code modulation. Later, this digital technology came to form the basis of computer development. FM radio and television broadcasting began and consumer markets were born. The new word "electronics" presaged the birth of new industries. As research and development intensified, computers and semiconductors came to be considered major products for the future.

Japanese Computers In 1951, a computer project started under the leadership of Professor Hideo Yamashita of Tokyo University with the cooperation of Toshiba Corporation. This was called TAC, Tokyo University Automatic Computer, and is a Japanese vacuum tube computer. After much effort, the 7,000 vacuum tube machine was completed in 1959.

In 1949, Mr. Bunji Okazaki of Fuji Photo Film Co. began the development of FUJIC. Working almost alone, he completed it in 1956. This computer, used for the design of camera lenses, was the very first machine ever manufactured and put into practical use in Japan. It is exhibited at the Science Museum at Ueno in Tokyo. Mr. Okazaki later moved to NEC and participated in the development of computers.

Before FUJIC was developed, relay type mechanical calculators were studied by the Electro-Technical Laboratory of the Ministry of International Trade and Industry. The resulting ETL Mark I was completed in 1952, and the ETL Mark II, in 1955. The logic formulas adopted for the circuit designs for the ETL Mark I were based on the 1935 Nakashima-Hanzawa theory of switching systems. This research was similar to the 1938 theory of Dr. C. E. Shannon of Bell Telephone Laboratories which attracted worldwide attention in the scientific community. The Japanese theory, however, was not announced overseas.

The invention of the transistor in 1948 by Bell Laboratories was a big shock to us. However, NEC succeeded in the trial manufacture of point contact type transistors in 1953 and then the development of various semiconductor products progressed rapidly.

In 1954 the parametron was invented by Dr. Eiichi Goto `of Tokyo University. The parametron, a kind of solid circuit, was remarkably stable compared to conventional vacuum tubes and was far less expensive than transistors, which were expensive at that time. Because of these merits, the possibility of using this new elements was eagerly discussed because it was an original invention from Japan.

The leading developers of the parametron were the faculty of Tokyo University, engineers at the Electrical Communication Laboratory of Nippon Telegraph and Telephone, and Kokusai Denshin Denwa Co., Japan's international telecommunications carrier. Under the guidance of Professor Hidetoshi Takahashi at Tokyo University, the PC-1 computer using parametrons was developed in 1958 and the PC-2 in 1960. At NTT Laboratory the MUSASHINO-1 started operation in 1957.

The late Professor Kenzo Jo of Osaka University was another computer pioneer. Under his guidance, research on an ENIAC type model was started in 1947 and completed in 1952.

Computer Development at NEC In the field of communications the parts which limted the performance of multiplex carrier transmission equipment were filters. The design of these filter was extremely difficult, and themethod used was direct experimentation. In 1955 Dr. Hitoshi Watanabe conceived of a new filter design theory that required calculations beyond the capacity of existing computers. As a result, NEC decided to build a computer using the newly invented parametrons. In 1955, research and development was started on the NEAC-1101 followed by prototype manufacture in 1958. This first computer was used not only for the design of filters but also for the development of new technology and products. Figure 1 shows boards that are on display at The Computer Museum. Based on this technology, NEC developed the SENAC-1 jointly with Tohoku University, and named it the NEAC-1102. Later, NEC delivered the NEAC-1103 to the Defense Agency Research Laboratory.

With the success of the NEAC-1101, I determined that NEC would develop computers as a new business. This led to the introduction of small-size computers for business use, called the NEAC-1200 series.

Transistor Computers In 1954, Dr. Hiroshi Wada, director of the electronics department of the Electro-Technical Laboratory of the Ministry of International Trade and Industry, began developing computers using transistors. The ETL Mark III using point-contact transistors was completed in 1956, followed in 1957 by ETL Mark IV using junction-type transistors.

When I saw the ETL Mark IV, I immediately decided to commercialize it at NEC and introduced this computer one year later in 1958, thanks to energetic efforts of the company's engineers. This computer, the NEAC-2201, was exhibited at the Paris AUTOMATH in June 1959. Soon after that, the IBM 1401 was put on the market, and the age of the second generation of computers, which used transistors, began.

Computer Systems NEC further improved the NEAC-2201 by adding additional memory and input and output equipment to create an "electronic data processing system," the NEAC-2203. Programming efforts were greatly reduced by the early development of a compiler, named NARC. NEC proceeded with the development of complicated numerical calculation routines such as programs for solving transportation problems, optimum path calculations, and linear programming. Through these experiences I came to fully realize the vital importance of software.

Japan's first on-line real-time seat reservation system, based on NEAC-2203 technology, was put into use at the Kinki Nippon Railways in 1960.

In 1967, NEC developed Japan's first time- sharing system using a large-scale NEAC- 2200 model 500 as the main computer. This was the end result of a long process starting with the NEAC-2202, which could be shared by 7 terminals based on the time division principle. Understanding the value of timesharing, NEC followed MIT's project MAC closely and used it as a model. NEC also called it the MAC system. With the first delivery to Osaka University, NEC's computer business evolved from small-scale, to medium-scale, then to large-scale, and from off-line to on-line systems.

Japan's Computer Development Three unique features have channeled the direction of computer development in Japan.

First, Japan's commercial computer industry started with transistor machines jumping over the first generation of vacuum tube-based computers.

Second, Japan's computer industry grew from communications technology utilizing technology, components, and elements which were developed for communications equipment. Thus communications and computers have developed a technologically close relationship in such things as circuit designs, analog to digital conversion, and adoption of solid-state circuitry.

In contrast, most American and European computer manufacturers began as office equipment makers supplying such products as punch-card systems. In their development processes, they converted their machines to electronic systems, and became computer producers.

Third, the Japanese government exerted helpful efforts during the formative period of the electronics industry, promoting telecommunications, consumer electronics, computers, and semiconductor products.

Through the first half of the 1960's, single purpose machines were classified into scientific use and office use. Then the trend shifted to multipurpose computers for general use.

In the mid-1960's, along with the increase in processing volume and diversification of usage, the family series machines became dominant. Manufacturers provided various scales of computers, ranging from small to medium, and later from small to large. All members of a family could share the same software. This was the age of the "line-oriented computer." NEC offered numerous models with the name of the NEAC-2200 series.

This family series had a big advantage over "point-oriented computers" in that software assets could be consolidated based on a consistent system design philosophy. NEC called this the "one machine concept." The vertical integration of the NEAC-2200 series oriented itself to centralized processing systems using large-scale computers. By the latter half of the 1970's, excessive centralization caused the hardware to become very large and complex, and at the same time, made it inevitable that software too must become voluminous and complicated. As a result, system flexibility and reliability were reduced and a remarkable amount of manpower was required for maintenance.

A distributed processing system was conceived to overcome these problems by processing information at the site of its generation and usage. In place of single super large computer, a number of comparatively small-scale computers and intelligent terminals incorporating computer functions are integrated through communications lines. This offsets the demerits of vertical integration and makes systems more economical. The "area- oriented computer" has both vertical and horizontal integration. Based on this conce

pt, NEC developed "DINA", Distributed Information processing Network Architecture, the architecture that incorporates the knowledge and experience gained from NEC's original communications technologies.

"C & C" As computers approach communications, communications is beginning to approach computers. Communications equipment has become digitalized and communications services have developed from the simple transfer of information to higher level services including processing and storage of information. In 1977, succeeding the announcement of "DINA" in the previous year, NEC announced the NEAX-61, the first digital switching system for telephone offices. In that year, I announced the concept of the merger of computers and communications at the Atlanta INTELCOM 77. Then in 1978, at the third U.S.A.Japan Computer Conference held in San Francisco, I announced this concept by using the phrase "C&C," which stands for the integration of computers and communications. Since then I have made "C&C" NEC's corporate identity.

From the technological viewpoint, "C&C" is the integration of computers and communications technologies. From the view point of "C&C"'s influence in social and economical world, it can be summarized in three points.

First, "C&C" can become an information- related infrastructure of worldwide scale.

Second, the constituent elements of this infrastructure will serve as valuable tools for solving various social problems, promoting economic and cultural development, and contributing to international mutual understanding.

Third, the effective use of information resources can overcome the limitations that restrict the optimum utilization of the world's natural resources.

"Man and 'C & C'" In the 1980's, "C&C" entered a new phase. The realizable ideal is that anyone, not just experts, can fully and easily utilize information systems in order to obtain a richer social and cultural life.

Human effort is facilitated by software. Due to the rapid increase in the amount of software required, a software crisis exists. "C&C" can only produce desirable benefits for humanity if software is produced efficiently.

"'C & C' and the World" The activities of AT&T and IBM show that the convergence of Computers and Communications is indeed the actual trend of the industry. AT&T, the world's largest telecommunications company, has entered the computer business. And IBM, the giant of the computer industry, is aggressively trying to enter the communications field.

Even now, the world's industrial map is in the process of being reorganized, centering around information and knowledge and equipment for handling them. NEC has been in the telecommunications business since its establishment over 86 years ago, and in the computer and semiconductor businesses for some 30 years. Because of this, NEC has been able to perceive and respond to major market shifts precisely.

Automatic Interpretation Telephones Throughout my 56 year career at NEC, I have believed it is my mission to create conditions by which anyone can talk to anyone else, at any place and any time. In the world today, mutual understanding between nations is terribly insufficient, and it can only be overcome through the unrestricted flow of information.

I have always thought that automatic interpreting telephone systems would be one of the keys to fully realizing "C&C." When this system is actualized, if the other party speaks to me in English, I can hear those words in Japanese, and vice versa, my words in Japanese will be conveyed to the other party in English.

If this automatic interpretation telephone system comes into wide use, it will not only make daily business extremely convenient, but it also will contribute greatly to the maintenance, of world peace. Because of the development of transportation and communications, people throughout the world have become able to communicate with each other at the grass roots level like never before in history. This means that people of one nation are coming to understand the ways of thinking and life styles of peoples of other nations. As a result, all the people of the world are beginning to recognize that they are all part of one humankind. If the barriers of language are removed by this automatic interpretation telephone system, communications and exchange at the grass roots level will further expand, and world peace may be realized.

Amdahl 470V/6

Amdahl 470V/6 by Amdahl Corporation, 1975. In 1975 Gene Amdahl, a major contributor to the design of the IBM System 360, announced his own company's first computer, the 470V/6. Amdahl's strategy was to produce computers which would out-perform IBM's top systems, but be completely compatible with them. In this the V/6 was successful, competing with the IBM 370/165 and 168. While selling for approximately the same amount ($4 million), the V/6 was rated at 3.6 million instructions per second with memory expandable up to 16 mega-bytes, making it almost twice as powerful as the 370/168.

The Museum's machine is serial number 2, the second machine produced by the Amdahl Corporation. Originally installed at the University of Michigan, the unit was later bought by American Cyanamid of New Jersey, and then by Major Computer, Inc.

Scelbi 8H

Scelbi 8H, by Scelbi Computer Consulting Inc., 1974. The Scelbi 8H (pronounced Sel- bee) was the first commercially-advertised computer based on a microprocessor. The first advertisement for the Scelbi appeared in March 1974, seven months before the debut of the Altair in January 1975. Nat Wadsworth, the Scelbi's chief designer, thought the computer would be used in scientific, electronic, and biological applications; hence, the abbreviated name Scelbi.

Designed for the hobbyist, the Scelbi 8H was based on the Intel 8008 microprocessor and was available both in kit form and fully assembled. It had 4K of internal memory, cassette tape and teletype interfaces, and a CRT based on an oscilloscope. Later on a combination monitor, editor, and assembler in ROM became available. Starting in April 1975, the company made versions with up to 16K of memory. These models were called Scelbi 8B's, the "B" standing for "business."

Wadsworth, an engineer for General DataComm Industries of Danbury Connecticut, became interested in th idea of a small computer for personal use after attending a seminar given by Intel on the 8008. He and several co-workers decided to build such a computer and in 1973 he left his job to work full-time on the computer. Scelbi Computer Consulting, Inc. of Milford, Connecticut was incorporated in August of that year. The development! of the computer suffered a severe s back when Wadsworth suffered a heart attack in November 1973. The company persisted, however, and announced their product in April 1974. The 8H was first advertised in the ham radio magazine QST because Wadsworth realized that many amateur radio hobbyists were "dyed-in-the-wool electronic enthusiasts." Just as orders started to roll in, Wadsworth had a second heart attack. In all, Scelbi Computer Consulting sold roughly 200 computers, losing $500 per unit.

From his hospital bed Wadsworth wrote a book to accompany the Scelbi 8H, Machine Language Programming for the 8008. The company published the book by offset printing a teletype output. The book was a hit; thousands were ordered. This success prompted Scelbi to concentrate on software for 8008- and 8080-based computers, such as the Altair. This shift in emphasis ultimately made the the company a profitable concern, but meant the early demise of the Scelbi 8's.

Donated by Carlton B. Hensley

[Based on "The Early Days of Personal Computer," by Stephen B. Gray in Creative Computing, November 1984.]

Sinclair ZX80 and ZX81

Sinclair ZX80 and ZX81, by Sinclair Research Ltd, 1980. Sinclair Research Limited, founded by Sir Clive Sinclair, announced the ZX80 in February of 1980. Based on the Zilog Z80A microprocessor it had an internal RAM of 1K. A 4K integer version of BASIC was also available in ROM. The machine used a membrane keyboard for input and a domestic TV as its display device. Programs and data could be stored on standard cassette tapes.

The ZX80 sold for under 100 pounds in the UK, $199 in the US-a major price break-through. This compared to about $500 for the TRS-80 and about $1100 for an Apple II with 16k of RAM. Manufacturing cost was kept low by use of the membrane keyboard and the single board design, in which all the circuitry including memory ROM, CPU, a total of 22 chips were mounted on just one printed circuit board.

The ZX81, also introduced in late 1980, had only 5 chips including the ROM, microprocessor, two 512 byte RAM's and the uncommitted logic array (ULA). The use of the largely untried ULA's (also known as gate-arrays) was a novel and bold move. The ULA performed all the functions not carried out by the processor, RAM or ROM, earning it the nickname "dogsbody." It replaced nearly 20 of the ZX80's chips. The ROM had a floating point Basic and, in contrast to the ZX80, the ZX81 could maintain a display on the screen while the processor was performing another task. This made animation possible, a major factor for game-playing users. In 1981 a 16k RAM became available for the ZX81 for just under $100.

At the end of 1981, Timex took over the US marketing of Sinclair's machines. The ZX81 was renamed Timex/Sinclair 1000 and sold for $99.95.

These models brought the computer well within the mass retail consumer market for the first time. Hundreds of thousands of ZX80's and ZX81's were sold-more than any other computer at the time.

Donated by Sinclair Research Limited of Boston.

Sectioned Direct View Storage Tube

Sectioned Direct View Storage Tube from Model 564 Oscilloscope by Tektronix Inc., 1962. The direct view storage tube (DVST) was invented by Robert H. Anderson in the late 1950's. First introduced in the Tektronix model 564 oscilloscope, it enabled the display of transient electrical signals. It was soon realised that DVST's could be used as display terminals with computers, and by 1969 Computer Displays Inc., Computek Inc. and Tektronix Inc. were all selling DVST terminals based on Tektronix tubes.

The key feature of the DVST is its ability to store a vector image without the need for constant refreshing. This brought down the price of computer graphic displays from, say $80,000 for the IBM 2250, to under $10,000, causing a vast expansion in the availability and use of computer graphics.

A DVST contains a writing gun, flood guns and a phosphor storage screen. The storage screen has an outer transparent conducting layer and an inner phosphor layer. When the write gun's beam is switched on it creates a postive charge where it strikes the phosphor as a result of secondary electron emission. This attracts the electrons from the flood guns which are on continuously, and causes the areas struck by the write gun's beam to luminesce without the need for refresh. The screen is erased by making the whole target more positive, effectively writing the whole screen and then lowering the potential, erasing the screen.

Donated by Tektronix Inc., Beaverton, Oregon

Prototype Von Reppert Calculating Machine.

Prototype Von Reppert Calculating Machine. This artifact is truly one of a kind. It is a prototype of a calculating machine built by its inventor Richard von Reppert. Patented in 1918, the von Reppert calculator could perform "the four fundamental calculations, addition, subtraction, multiplication, and division, as well as other useful commercial work, in a practical manner." Von Reppert sold this and several other patents relating to mechanical office machines to the Underwood Company in 1920.

Over the course of his career von Reppert received over 40 patents either in conjunction with others or on his own. These include two patents issued by the German and French governments, and 8 for floating point arithmetic mechanisms for mechanical calculators. In addition ' to being a solo inventor, von Reppert also worked for the Underwood Company and IBM for many years.

Donated by Erwin]. and Richard W Reppert

Bill Gates' Teletype tape to input the BASIC interpreter for the Altair

Bill Gates' Teletype tape to input the BASIC interpreter for the Altair. When Harvard students Bill Gates and Paul Allen read about the Altair in the January Popular Electronics, they decided that they might make some money by creating an intrepreter for BASIC on this new microcomputer. With the 8080 instruction manual and the Altair schematics, they produced the code, fitting in less than 4K of memory, within two months. They called Ed Roberts in Albuquerque and he said, that he'd buy from the first person that showed up with one. Paul Allen took the tape to MITS where he found only one machine that had 4K of memory. When he loaded it the teletype replied with "READY." Everyone at MITS was excited: they had never seen the machine do anything. Shortly thereafter Ed Roberts arranged to bring Bill Gates from Harvard to complete the implementation and Bill never returned to school.

The Allen-Gates Altair BASIC was listed in the MITS catalog like every thing else it sold, and each purchase earned the authors royalties. Nevertheless even before the first release a pirated version of Altair BASIC was in free-flowing circulation. Gates, then nineteen, wrote a letter to the Altair Users' Newsletter entitled an "Open Letter to Hobbyists." Gates noted that while he and Allen had received lots of good feedback about the interpreter, most of the people praising it hadn't bought it. Gates asked:

> *Why is this? As the majority of hobbyists must be aware, most of you steal your software. Hardware must be paid for, but*

software is something to share. Who cares if the people who worked on it get paid?

Eventually the widespread use of the BASIC interpreter was to help Gates. When other computer companies came on line and needed a BASIC, they went to Gates' company. He had created a de facto standard for microcomputers.

Blue Room Blues

Imagine you worked down a two mile-long tunnel half a mile underground. There you were expected to sit for eight hours a day studying the blinking yellow screen of a spotless grey machine in a cement room devoid of decoration and lit only dimly by blue lights. Once you arrived you were not allowed to leave until the end of your shift, when you took a bus back to the barracks you called home, miles from civilization.

This environment was the workplace for radar operators of the Air Force's North Bay Canada SAGE installation. Here operators monitored the atmosphere of the northern hemisphere, on the lookout for Russian bombers and missiles. "The Blue Room," as the radar center was called, was studiously designed to minimize the fatigue of the operators: the lighting was indirect blue flourescent, to cut down on eye strain from the blinking yellow radar scopes; electric lighters and ash trays were built into the consoles; and the color of the equipment was a neutral battleship grey. To ensure efficiency, personnel were required to keep their consoles clear of clutter. In fact, the only extraneous object visible in the room was a large cardboard vampire bat attached to the ceiling, in deference to the room's cave-like qualities. However, as the Museum later discovered, this was not the only individual expression the operators allowed themselves.

When the equipment from th North Bay SAGE installation arrived at The Computer Museum, cleaning revealed interesting evidence of how the operators viewed their job. Each console has several knobs covering recessed switches. When these knobs were unscrewed the backs were foun to be covered with graffiti written b the operators. The hidden message ranged from the banal to the unpublishable. While ostensibly observing the rigid regulations regarding a spotless work area, the operators still managed to express themselves clandestinely.

Here is a selection of the messages left by the operators hidden in their consoles:

"Put this back"
"HELP"
"Art Clark 1979"
"Bravo Crew is the pits"
"Look on the other knob"
"Superbowl XXII"
"Send the Cowboys to the superbowl"
"Don't you feel useless"
"$25"
"Hi Jack"
"Help I'm trapped in here"
"No step take off Hey"
"1 May '79"
"I can't stand it"

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Highlights from

The Computer Museum Report

Volume 15 ---- Spring 1986

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The Museum Mouseathon

Maze layout used in Mouseathon finals
The maze was selected to have a number of routes to the center which had similar length, but a varying number of corners. This offered a subtle test of the mouse's strategy in choosing between rapid cornering and acceleration down a straight. Note also the zig-zagging required in the final approach.

The maze consists of 16 x 16 squares, each 18cm on a side. The walls are 12mm thick, 5cm high, painted white with red tops. The target is the center, and the start is at the 'bottom left' corner. The running surface is chipboard, painted black with non-gloss emulsion paint. The walls are composed of removable segments connecting posts at the corners of the squares, so that mazes can readily be changed.

What is a Micromouse?

A micromouse is a mobile sensing robot that can negotiate a maze. The contest rules state that the mouse must be self-contained, cannot use combustion as an energy source and cannot leave part of its body behind while in the maze. It cannot jump over, climb, scratch, damage or destroy the maze walls. It must be less than 25cm in both length and width; there is no height restriction.

Most mice use active infrared sensors to locate the walls. A pulse of 1000 nanometer infrared is shone downwards from a vane that extends over the walls adjacent to the mouse. The red top of a wall sends back a strong reflection, while the black floor does not. Some mice, notably the Finnish team have used acoustic sensors. The Noriko mice used the position gyroscope as an additional sensing device to preserve accurate control during rapid cornering.

The most popular microprocessor used to control the mice is the Z80. In 1981, Alan Dibley went so far as to saw off the keyboard of a Sinclair ZX80 computer and use it intact to control his Euromicro finalist, 'Thezeus'. Indeed, the 'Thezeus' series were largely built out of bits of junk-piano wire, rubber bands (for tires), and parts from radio-controlled models.

Championship Rules similar to rules applied at the Museum Mouseathon)

Each mouse has 15 minutes in the maze. It can make as many runs as it likes, and the fastest 'inward' run from the start to the center is recorded. If a mouse 'gets into trouble', it must be taken out of the maze and restarted at the beginning. No information on the maze can be fed to the micromouse. For full rules see IEEE Micro, Vol 4 No 6, (1984) pg 86; for information about future contests, contact Micromouse Committee, IEEE Computer Society, 1730 Massachusetts Avenue NW, Washington, DC 20036.

Origins

It all began with a 1977 announcement in Spectrum magazine that the time was ripe for microprocessors to put on wheels for a self-controlled ride. The challenge was to build a mouse that could find its way to the heart of a maze, remember it, and then run the course as fast as possible. The IEEE Computer Society formalized the competition, specifying maze and mouse dimensions, and trials took place throughout 1978 with a final race at the National Computer Conference in 1979. The winner was the only mouse among the 24 entrants that made it to the finish! The rest of the entrants got stuck or confused, or just failed to start. But the contest looked like fun. These small mobile robots require hardware for propulsion, steering, guidance, wall and track sensing and software for mapping and strategy The fixed set of rules constrains the problem and the contest provides a quantitative measure of progress.

International Micromouse Racing

The idea has taken off in Europe and Japan. Under the impetus of Dr. John Billingsley, mice from the UK, Finland, West Germany Switzerland have competed in European championships held every year since 1980.

Since the first Japanese micromouse contest in 1980, the Japan Micromouse Association has grown to 800 members spread throughout the country. The association has a permanent board of directors, consisting of senior academics, industry executives and officials of the Japan Science Foundation. A bimonthly magazine 'Mouse' is published, covering micromouse events worldwide.

In 1985 the Japan Micromouse Association held a World Micromouse Contest coinciding with the World Expo in Tsukuba City, Japan. With support from the Japan Science Foundation and NAMCO Ltd., the Japan Micromouse Association invited teams from Britain, Finland, Germany,

South Korea and the United States to compete. It soon became clear that the visiting mice were no match for the Japanese entrants. The first five prizes all went to mice from a single Japanese microcomputer club-the Fukuyama Club, from Hiroshima Prefecture.

Micromice in the US

Although the idea originated in the United States in 1977, it has not caught on. In 1984, in an effort to rekindle US interest, the Japan Micromouse Association presented the IEEE Computer Society with an official micromouse maze for use in the US contest where participants in the world contest would be selected. Mappy, the official mouse of the Japan Micromouse Association was loaned together with the maze. In the Spring of 1985, The Computer Museum and the IEEE Computer Society agreed to site the maze at the Museum, develop a micromouse exhibit and hold a special inaugural event.

The Museum Event

Dr. Peter Rony of the IEEE Computer Society and Dr. John Billingsley from Portsmouth, England kicked off the Museum's race week with a lecture/ demonstration on Sunday, November 17. Dr. Billingsley demonstrated three mice he had brought from England.

A group from The Japan Science Foundation, NAMCO and the Fukuyama Club were also invited. Mr. Hirofumi Tashiro, Secretary General of the Japan Micromouse Association and Manager of the Director's Office at NAMCO Ltd. led the group. Three members of the Fukuyama club came: Mr. Masanori Nomura, a trained veterinarian, Mr. Masaru Idani, system technical researcher for Japan System Design Co. Ltd. and Mr. Eiichi Fujiwara. The IEEE Computer Society arranged for Mr. Key Kobayashi, an interpreter to attend.

The Inaugural Run

John Billingsley's three English mice rapidly cleared customs at Logan airport in Boston where they are used to seeing weird electronic contraptions. 'Thumper', the 1981 European champion by David Woodfield, runs on four wheels and turns by swivelling his wheels, not by rotating the whole body. His large and heavy frame tends to thump the walls, hence the name. His ability to talk, apart from being very funny, is used for diagnosis. 'T6; the latest in a series of 'Thezeus' mice by Alan Dibley, and 'Enterprise; the 1984 European Champion by David Woodfield are both three-wheeled mice with DC motors to provide propulsion on the back wheels and an optical distance counter on the steered front wheel. All three use the Z80 microprocessor.

The 1985 World Micromouse Contest at Tsukuba Fifteen contestants from 5 overseas countries and 120 from Japan competed.

Though delicate, the mice survived the journey intact, and they were checked out on a trial maze. It soon became apparent that Thumper was most confused, and T6 was steering straight into the walls. Preferring not to attribute this performance to jet lag, we suspected that the maze itself was not giving the infrared signature required by the mice. The mice detect the walls by using active infrared sensors that stick out above the walls of the maze and look down. The tops of the walls are meant to be reflective in infrared (around one micron wavelength) and the black floor of the maze is meant to absorb infrared. However, the floor of the maze, though black, looked rather shiny in the infrared, so after obtaining permission from the IEEE Computer Society, we covered the maze floor with a thick coat of the mattest black emulsion we could find. Thumper and T6 still occasionally went 'blind; so we began to suspect the walls. Using Thumper as an infrared reflectometer, we found that the dull red plastic layer that covered the tops of the walls was actually a very poor reflector of infrared. So we covered all the wall tops with strips of highly infrared reflective red sticky paper, and this solved the problem.

At the start of the Sunday lecture, Peter Rony spoke on behalf of the IEEE Computer Society, presenting the Museum with the loan of the official maze, and encouraging future mousebuilding activities in the US. John Billingsley then described the history of European micromouse events and demonstrated the three English mice. Thumper, though slow and lumbering, makes up for it by his speech, saying "I will find the shortest route" as he pulls off from the start. Apparently at random, he sings out with a repertoire consisting of remarks such as 'I hope there are no cats in here; 'my work is never done' and'I could do with a restmy wheels are killing me!' When comparing Thumper to the later mice, it's hard to believe that he is more than all talk and no action-he was actually the European champion in 1981.

Enterprise and T6 learn the maze after relatively little exploration and take advantage of the straight passages with bursts of acceleration.

The Mouseathon

After 21 hours in the air, the Japanese participants arrived late on the Thursday before the Saturday event. Refreshed the following morning, they unpacked their mice-all members of the 'Noriko' series. The older X1 and X2 performed well at once, but X3 and X4 seemed a bit worse off for the long travel, and needed some attention from the chief engineer, Mr. Idani.

After a burst of speed down a straight, T6 brakes just in time to round a corner.

Mr. Tashiro watches Mappy at the maze's start NAMCO, a large manufacturer of computerised games and toys, built 10 identical show mice in 1981 to promote interest in micromouse racing. Modelled after a popular Japanese cartoon character, Mappy plays the role of a mouse policeman, scouring every alleyway of the maze to find a troublesome stray cat. With siren blaring and baton waving, he bears down on the center of the maze where he spins around to burst a balloon with a pin mounted on his tail. Then he - races back to the starting square, sirens still blaring and lights flashing, and shouts "I got 'em!" in Japanese.

Mappy will be demonstrated regularly at the Museum while on loan from NAMCO.

An enthusiastic crowd of over 400 people showed up for the event. Throughout the morning and early afternoon time-trials were held. Each mouse had fifteen minutes in which to make its best run to the center (see rules box). All mice completed the maze, except for Noriko X4 which never really got going. Noriko X1 came in fastest, at 14.8 seconds in contrast to Thumper who managed to talk his way through the maze in 3 minutes. Mappy performed a couple of his noisy runs, greatly entertaining the audience.

The race's judges then took their places: Susan Rosenbaum, governing body member of the IEEE Computer Society and volunteer in charge of US micromouse activities, affectionately known as 'micromom; Gwen Bell, the Museum's president, Hirofumi Tashiro and John Billingsley.

The maze was changed to make sure that memories of the time-trial maze could not give any mouse an unfair advantage and the race then began with the mice competing in the order in which they qualified.

Noriko X4 still failed to wake up, but X3 completed a run in just over 13 seconds. Next, Thumper talked his way into the corners, so badly out of alignment that he had to be retired. T6, which must be the quietest mouse ever built, came in at 37.2 seconds. Enterprise performed reliably again, never slipping or needing any kind of adjustment. But his time of 28.1 seconds proved no match for the Japanese.

Now the two fastest Noriko's battled it out. Although the Noriko mice carry out a lot of apparently redundant maze exploration at the outset, they make up for it with speed and cornering agility once they find the shortest routes. It was breathtaking to watch the slalom as they swung aroung the final zig-zaps towards the finish. Several times the Noriko's got stuck a hair's breadth from the finish and had to be carried back to the start. In the end, powered by a freshly inserted heavy duty Nicad battery pack, Xl made a lightning fast run of only 10.85 seconds, just over half a second faster than X2's best run of 11.55 seconds.

Judges Susan Rosenbaum (left), Gwen Bell (center), and Hirofumi Tashiro with john Billingsley commentating.

Gwen Bell awarded the prizessilicon wafer pendants, hung around the necks of the human participants, not the mice.

The Future

The Museum will hold more races when new mice come forward to challenge the Japanese and Europeans. There are encouraging signs-several groups took notes at the races, saying they planned to build micromice with better maze-solving strategies. For those who want to try their hand at the software side of micromouse racing, NAMCO Ltd. makes a kit that can be purchased via the IEEE Computer Society.

John Billingsley is now promoting robot ping-pong, or 'robat'. Contestants mount their payers at either end of a special table with controlled lighting and a mechanism to serve the ball. The players essentially consist of a bat fixed to an x-y plotter mounted vertically together with a vision system.

The Museum plans to collect micromice and provide a venue for future international sporting events!

After the award giving, from left to right: Eiichi Fujiwara, Masanori Nomura, John Billingsley, Oliver Strimpel, Masaru Idani. Mr. Idani and Mr. Fujiwara hold 1st and 3rd place winners, Norikos XI and X3. The Noriko series employs a 'wheelchair' drive: two wheels have drive motors and steering is accomplished by driving them at different speeds. Fore and aft are wheels, castors or skids to provide stability. The newer Noriko's are DC motor driven, the older ones using stepper motors. A home-made position gyroscope with its axis mounted horizontally gives the mouse an accurate measure of how much it has turned, a critical piece of information when the wheels are liable to skid during very rapid cornering. These mice also have easily inserted ROMS, used to give the mouse different strategies, depending on the maze. ROM- swapping and tweaking of potentiometers is not allowed in European contests where a more rigorous criterion of micromouse self-sufficiency is applied.

A Personal Odyssey
From the First 16-bit Mini to Fault Tolerant Computers

Gardner Hendrie

> **Throughout my career as a computer designer, I have set out on explorations into the unknown. Over and over again I undertook the design of new computers without the foggiest idea of how to do it. Over the last twenty years, I was involved with-three different machines at three different companies. In what follows, I have corrected all the dollar amounts for inflation so that direct comparisons can be made.**

1964: The First 16-bit Mini

In 1964, three companies competed in the mini-computer market, even though the name had not yet been invented and they were called realtime control computers. DEC did $37 million in business; Computer Controls Corporation (CCC) $50 million; and Scientific Data Systems (SDS) $67 million business. SDS which grew to $134 million in the next year, was clearly the successful company of the three. Then in the late sixties, SDS was bought by Xerox for about a billion dollars and became SDX. In the sixties, Xerox disbanded this fairly expensive experiment. In 1965, CCC was purchased by Honeywell, surviving until the early seventies when it disappeared into the larger organization.

In 1964, DEC was selling the PDP-5, the precursor of the PDP-8, for $95,000. CCC was selling the DDP24, and SDS the SDS 910 and 920, each for about $300,000. The machines had 8K bytes of memory and the basic i/o device was the flexowriter, the precursor of the ASR 33 teletype which provided a keyboard, a printer, and a paper tape puncher and reader. Software existed but was not elegant. The operating systems would run on 4K words of memory and on a FORTRAN compiler with 8K words. Back-up storage was done on magnetic drums that ranged between 32,000 and a million bytes.

At that time, I had been earning a living for ten years as an engineer. My inflation adjusted salary was $65,000. If you look at salaries today they are equivalent. A VW bug cost just over $5,000. A lot of things stay the same forever, adjusted for inflation.

I had designed an industrial control computer for a division of RCA that ceased to exist two years after the computer was built. When I designed that machine, I had never designed or even worked on the design of a digital computer before, nor had I taken a course in digital computers. I did have an elementary course where I learned plug board programming on an old Burroughs machine, so I had some vague idea of the basic principles of computers. The experience was my education. The computer seems absolutely prehistoric by today's standards. It took 56 microseconds to add two 24bit numbers and cost roughly half a million dollars. NASA used this machine for checking out the main Saturn booster stage on the Apollo missions.

Lowell Bensky, whom I had worked for at RCA when I was out of college, asked me to join CCC. The VP of marketing at CCC believed that if we could build a $75,000 computer to go along with the $300,000 DDP24, a lot more machines would be sold. I left Foxboro to build that machine for CCC. At the time, the competition was the PDP-5 and CDC's 160. In my view, the CDC 160 with its short word length, a basic instruction that could not address all of memory, and relative, indirect and chained indirect addressing, pioneered the architectural concepts that made the minicomputer feasible. It was a commercialization of Seymour, Cray's first machine at CDC, The Little Character, that can be seen at the Museum and is featured in "The End Bit" of this Report.

CCC was in a good technological position to produce a competitive computer. It manufactured a set of 5 megaherzs logic cards, each with a couple of flipflops of four or five and gates. Customers bought a card cage, plugged the cards in and then wire wrapped all of the cards together and interconnected them on the back. The company also had a memory division that built one of the more advanced devices for the time with a 1.7 microsecond cycle time. DEC's PDP-5 had a six microsecond cycle time memory and CCC's DDP 24 had a five microsecond cycle time memory. The question was-what should one build with this fast memory and circuit technology?

I became infatuated with the idea of building a fast, short-word length machine. 12 bits looked a little short. 14 bits looked just about right. It gave you enough code for a reasonable instruction set and addressing range. I didn't want to make it any longer than I had to because it would make the machine more expensive. In those days, the computer and its memory were the dominant costs not the i/o equipment. After a couple of weeks at CCC, I had an outline of the specifications.

Then, on April 26th, 1964, three weeks after I joined CCC, the bomb shell hit: IBM announced the 360 and declared that the six-bit character was no longer going to be a standard for storing alphanumeric data. Instead, it would be an eight-bit unit called the byte. It didn't take much to say, "I'll bet if we increase the cost of the processor ten percent or so and lengthen the word to 16 bits we'll make up for the cost in the market appeal of a machine that can store two eight-bit bytes on the new standard just set by IBM."

By August 1964, the specs had been completed on the DDP-116. In October the machine was announced and the first shipment was in March of 1965. Only 200 were ever sold.

In 1965, CCC announced a new logic family called the Micropac using integrated circuits. These were the first commercially available integrated circuits that were designed by CCC and subcontracted to semiconductor manufacturers. The most reliable manufacturer for these flat packs was Westinghouse. CCC had also by this time designed a less than one microsecond cycle time memory.

When the 116 was shipped in March, 1965, we immediately started to work on a low cost version, the 416, and a higher cost version, the 516. Shipped in September, 1966, the 516 had a .96 microsecond cycle time and sold for $82,000. The 416 built with a hobbled 116 instruction set was supposed to cost $5,000 and sell in large quantities. While it was estimated that only 130 of the more expensive 516s would be sold. Very few 416s were ever bought, but over 2000 516s. Then a 316, lower-cost, slower machine was built to compete with DEC's lower cost 12-bit machines that seemed to be flooding the world.

After CCC was bought by Honeywell a process of decay had set in. I stayed at Honeywell working as an engineering manager and then as a product manager in marketing. Prime was formed to step into the vacuum that Honeywell left in getting out of the minicomputer market. Every machine up through the Prime 750 was object code compatible with the DDP-116 and 516.

1973: The Advent of Microprocessors

In 1973, I had the opportunity to join Data General to design a microprocessor-based computer. They had a successful 16-bit minicomputer line based on the NOVA and they wanted a NOVA on an MOS chip. My only problem with this opportunity was that I didn't know what an MOS transistor was or how it worked. And once again I was off on a new odyssey: I didn't have the foggiest idea of how you did logic with microprocessors. Otherwise, I was excited about the challenge and took the job.

The first microprocessor, Intel's 8008, a P-channel, 8-bit device, had an accidental birth. It was the outgrowth of a contract with Datapoint who had specified the architecture for a microprocessor. After the contract period had expired and both Texas Instruments (the alternate supplier) and Intel had not delivered, the contract was cancelled. TI dropped the project but Intel chose to continue it and fund it internally. The rest is history in the microprocessor business.

Data General decided to use the newest technology: n-channel processing, which produced much faster MOS transistors, and silicon gates which provided additional interconnect capability. The decision was made to build the machine in-house at DG's own semiconductor facility, which had been operational for about a year. The hardest part of designing a 16-bit computer on a single chip at a time when 8bit computers represented the state of the art, was fitting it all onto the available area of silicon. The first decision was to use an internal 8-bit data path and arithmetic unit. I also decided to go to a serial i/o bus to solve some of the pin limitation problems. The adder would be the slowest part, even with carry predict circuits.

A second person was added to the project: a circuit designer in Sunnyvale. He showed me that registers are cheap and random logic terrible. With that information we decided to make a micro-coded machine, even though I had never done that before. In the process I picked up a Fairchild application book that had a picture of a PLA (programmed logic array) in the back. It looked like a nifty idea for instruction decoding. It also occurred to me that if you put a second PLA on the rear end of the first, all the decision making could be done by looking at the results of operations and deciding what to do next. An area efficient design was developed with two PLAs for the sequencing. The chip also had a real-time clock in it and generated refresh addresses and refresh timing for the dynamic namic rams during periods when memory was idle and internal processing was going on in the chip.

It took me about a year to get educated and design the chip. Then we hired a technician to build a TTL simulator who put 1,000 i.c.s on wire wrap boards. He hand wired 20,000 connections to build the simulator and had it running in six months. It then took eight months to hand draw the IC layout. Because of the difficulties of the new process and the large line size, another year was consumed in getting all the details ironed out in order to make production units. Thus, it didn't ship until early 1976.

DG's single-board $1,500 computer with the 8-K bytes of memory on a single board was equivalent to the DDP-516 that sold for $82,000 a decade before. Adding a card cage and i/o, the price of the micro-Nova increased to $8,300; one-tenth of the price of the previous decade.

1980: Fault-Tolerant Computers

The decision to start Stratus in 1980 was based on the apparent need for fault-tolerant computers in commercial on-line data processing environments as opposed to those built for scientific ones. This led to a new exploration since I didn't know anything about the subject. When I went to the MIT library I was surprised to find volumes one through nine of the Proceedings of the Conferences on Fault-tolerant Computing oriented toward research and aerospace applications. The 1962 Apollo Guidance Computer built for NASA (that can be seen at the Museum) was a fault-tolerant machine. Only Tandem Computers had moved the technology to the commercial world.

Starting in 1974, Tandem had a 100 million dollar software intensive business by 1979. Any fault-tolerant system needs to be redundant until somebody invents parts that can heal themselves. The basic principle of Tandem was two computers side by side that could work with common mass storage. Errors are detected through memory parity or a stall alarm. A failure would restart the program at the last checkpoint on the backup machine.

This software intensive approach could be a major problem with many terminals involved in online data processing applications. If the system could allow some slowing down when a failure occurred, then the backup machine could be doing something useful driving normal operation. This solution had been invented in days of expensive hardware in 1974.

Stratus decided to build fault-tolerant hardware and not software. We chose a technique that required each element of the machine, such as the cpu board, to be able to detect its own failures. The simplest way to do this is to build two sets of everything and just before anything is sent out on the system bus, a comparator checks the two. If they aren't the same, the board is broken. With two boards, the work goes to the other board. This requires four sets of logic, which sounds expensive, but it isn't. I guess I should point out that we didn't figure out the scheme we used until after we raised the money for our startup.

One of the first things we did after the architecture was determined, was to put a red light on the end of a board to signal failure. Then field service didn't have to figure out what was wrong, but just take out the board and send it to the factory. Then we asked ourselves, "If field service isn't needed for fault detection, why are they needed on the customer site at all? Have the customer do it without a service call." This creates a new problem. The replacement has to be a fool proof insertion, without any special switches or an umbilical cord which might confuse the customer. In the final design, any board could be pulled out of a running machine and put in another one without anything happening.

Another problem was uncovered. How would we know what board to send to the customer for replacement? Could we depend on a secretary to pull out a bad board, read the model number, and accurately repeat it on the telephone? We thought that would be too much to ask. We added a feature that let the system read the slot location, the error state, the model number, revision level, and serial number of the bad board, finally throwing in a modem so that the computer could report the bad board directly to field service at Stratus. The electronic mail message to the Stratus computer reports what failed and all the details of the occurrence. The typical scenario is that the Stratus home office then calls up the customer and tells him that his machine has a failure. The customer doesn't know it until he's told. By then, the replacement board is on its way by Federal Express.

We also decided that there was no benefit in designing your own instruction set. It's fun, but a fool's errand if the objective is to make money. So we used commercially available microprocessors. We chose the 68000, the best machine in late 1979. Since we wanted to make a virtual machine, we found that the 68000 could not cope both with a page fault and restart, and at the same time go out and get a page from disk and lead it into memory. So two 68000s were put on each cpu board. The next step was to have part of the operating system run in the second 68000 in addition to the page fault handler. Then more and more processors were put in the system to run both operating system code and user code.

The second Stratus multiprocessor system has six microprocessors running concurrently out of a very large shared memory. The four microprocessor version has a .125 microsecond memory cycle time and sells for $200,000 with 4,000K bytes of main memory and a 400 megabyte disk.

A Continuing Odyssey?

It has been an adventure for me to be associated with all these computer projects. Once again I'm on a quest and will only be able to describe the avenues I explored when it is all behind me.

See How They Ran:

A Set of Classic Film Clips Showing Computing From 1920 to 1980

"See How They Ran" was assembled at the Museum and is shown there to illustrate the integration of hardware, software, other technologies and the environment of work in computing over time. Some clips were chosen because they show pioneering projects and others the flavor of the times. As a whole the film provides, in 35 minutes, a glimpse of the various components that have changed over time: size, ease of use, programming and software, and the attitude towards computers and computing.

The films were made for a variety of purposes and have different levels of sophistication. The common link is that each film is contemporary with what it is showing, very little historic interpretation is made at all. Further, all of the films were made with direct involvement of the people involved with computing at the time, rather than interpretations from other fields. The only exception is the silent ENIAC film taken in 1947, edited and narrated by Professor Arthur Burks, who was a graduate who worked on the machine, in 1981. Because of these attributes, the film has very unique pedagogical qualities-providing new insights and entertainment to trained computer professionals and the spirit of the tradition to students and interested people.

The Museum will now make this film available to others in order to serve our purpose as an educational institution.

IBM Punch Cards, 1920

This film about data processing before the computer illustrates one of its clearest antecedents.

The use of the punched card as a means of electro-mechanically storing and manipulating information was developed by Herman Hollerith for the U.S. Bureau of the Census for compiling the results of the 1890 census. The general idea of storing information on punched cards dates to the late 18th century and the use of punched cards to control the patterns woven in fabric by looms built by, among others, Joseph Jacquard. After developing machinery for the Census Bureau, Hollerith formed the Tabulating Machine Company, which later was incorporated into International Business Machines Corporation (IBM) by Thomas J. Watson. By the turn of the century several different companies were making punched card data processing systems for a wide variety of growing business uses.

The film clip shows a punched card operation of the 1920's. Women dressed in long dark skirts and white blouses transfer cards from one mu chine to another, and index and file them for storage. Each machine performed only one operation such as sorting cards, adding data, or printing, so the women were required to physically move the data from one machine to the next to perform a series of operations. Such systems were used through the early 1960's, when they were almost entirely replaced by computers.

ENIAC,1946

Late at night on February 13, 1946, the legend goes that the lights dimmed at the Moore School of Engineering at the University of Pennsylvania, when the 18,000 vacuum tube ENIAC was completely turned on.

Developed by J. Presper Eckert and John Mauchly ENIAC stood for Electronic Numerical Integrator And Computer. The group who participated in the building and use of ENIAC met to discuss the next machine. In these meetings, the concept of the stored program computer was discussed and it can be said that ENIAC led directly to the development of the stored program computer.

The film show ENIAC in use computing ballistics tables which predicted the flight of a projectile under various conditions such as the wind speed and direction, the size of the shell and firing charge, and the inclination of the gun barrel. Before ENIAC, it took several people using desk calculators many months to complete such a table for a given trajectory. ENIAC could compute the trajectory faster than real time; 20 seconds for a thirty second trajectory. However, this computation required two days of setting up the program to run on the machine. The film shows several women in knee- length skirts and bobby socks, clip- boards in hand, setting the switches on the front panel of the machine. In addition, wires had to be replugged to connect different logic components. Programming ENIAC, thus, consisted of determining how to wire the various functional components and set the dials to solve the problem.

Automatic Computing With EDSAC, 1951

Maurice Wilkes who built EDSAC narrates the film. Wilkes attended a summer school on the ENIAC held at the University of Pennsylvania in the summer of 1947, afterwhich he returned to Cambridge University in England and started to build EDSAC, the first computer in regular operation to truly incorporate the stored program concept.

Two features, illustrated in the film, made EDSAC a more efficient computer to use and program: the internal storage of the program and the use of subroutines. Maurice Wilkes says, the film "can be seen as an advertisement for subroutines." The EDSAC programmers recognized that there were certain sets of instructions which they repeatedly used. Instead of reprogramming the operations each time they used them, they kept a copy of the set of instructions encoded on paper tape. Whenever they needed to include that particular routine in their program they simply copied the master tape onto the tape of their program. This improved the speed and accuracy of programming, and was the forerunner of higher-level, more powerful programming languages.

Whirlwind I: Programming at 3:00 A.M., 1953 From "Making Electrons Count"

This film clip was produced by MIT to demonstrate the use of the Whirlwind Computer Project. During the early period of computing in the US, computers were built almost exclusively for the federal government, particularly the military. While occasionally these early computer projects were undertaken by federal agencies or private organizations, the majority were developed at universities as government projects. The universities saw the benefit of computing for a wide variety of research and educational purposes. In the film a medical research scientist learns how to program the Whirlwind to perform a calculation for optical lens design. His experience illustrates what it was like to work on an early computer: the difficulty of writing a program which worked, the separation of the programmer from the machine, and how the computer ran only one program at a time.

Both the EDSAC and Whirlwind films were used by universities to show the advantage of using computers to do very difficult problems in a research and educational environment. Prior to this time, there were common statements that three to fifty computers would be sufficient for the world's problems. These films quickly provided evidence that every university, and then every department in every university, and every research lab would be soon writing applications to justify the addition of computers.

FORTRAN 1957 By 1954, it became clear that computing was to grow as an activity and that a scientific language was needed to ease programming. FORTRAN, short for "formula translation" was being developed then by IBM and remains an important language today.

However, by 1957 it had not reached terribly wide acceptance. Many early programmers were emotionally committed to program in machine or very low-level languages. This film makes the case for programming in FORTRAN providing a very simple problem to contrast with machine language and shows a very serious advocate for this radical change.

Ellis D. Kroptechev and Zeus, A Marvelous Time-Sharing System, 1967

This student-produced film from Stanford University is a humorous spoof of the trials and tribulations of a college hacker condemned to use batch processing Story set in the university

computer center and cafeteria provides an accurate feeling for what it was like to program a computer during the 1960's.

It also illustrates an important transition from punched card batch processing computers, to time-sharing computing using teletypes and then video terminals.

Ellis D. Kroptechev is a "man with a problem, a girl and a deadline." We watch as Ellis struggles with jammed card punches, and numerous errors to complete his program in time and meet his girl friend. Ellis has to wait hours for his turn. Finally, when his program is run unsuccessfully, he must work through the listings by hand to find the errors. He cannot use the computer to assist him, in fact, he never even sees it, he can only submit his program on punched cards to the operator. In his final moments of despair Ellis is saved by Zeus, A Marvelous Time-Sharing System, in which he can directly enter the program into the computer, debug and run it himself. In no time his program runs perfectly, and in triumph Ellis walks arm in arm with his girl friend into the sunset.

STRETCH: The IBM 7030, 1960-1981

This unique film, produced for the Museum, shows one of the first supercomputers ever built.

The IBM 7030 or STRETCH as it was called was designed between 1954 to 1961 to tackle the most advanced and demanding problems of scientific computation. It embodied many technological breakthroughs, and had a great influence on later IBM machines. The concept of the "byte" versus the "bit" was developed to represent an 8-bit "syllable" of the 64-bit long Stretch word. Then in 1964, the 8-bit byte was made into a de facto industry standard with the IBM 360.

Only seven STRETCH's were ever built.

The one filmed was pieced together for the Brigham Young University computer center from the original machines from Los Alamos and from Mitre, before it was shipped to the Museum. By then it had become a dinosaur with only a 256K primary memory of 64-bit words requiring a very large room and a team of attendants.

Little Character

Little Character, by Control Data Corporation, 1959. The Little Character was a prototype computer developed to test the concept of modular circuit design at Control Data Corporation shortly after its incorporation in August 1957.

When he joined the young company in 1958, Seymour Cray tried to persuade president William Norris that there was a market for a low-cost, high-speed computer designed for scientific applications. Norris was sufficiently convinced to let Cray develop the Little Character. The machine used a small number of standard circuits made by loading transistors onto small circuit boards. These in turn were connected via a hand-wired backplane.

The Little Character vindicated Cray's modular design and Norris was convinced. The company then used the ideas embodied in the Little Character to build the Control Data 1604, a computer aimed at the low-priced scientific market.

On loan from Control Data Corporation, Minneapolis, Minnesota

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Highlights from

The Computer Museum Report

Volume 16 ---- Summer 1986

Cover "Colors of Chaos"
Julia set of (0.1 + 0.17i)sin(z) after 35 iterations by Robert L. Devaney, Boston University (see article)

Contents of Highlights

THE PRESIDENT'S LETTER

This young Museum is still filled with first experiences. Two are especially worthy of attention: three of our first interns have achieved important career objectives and the first members survey has been completed.

The Museum's first intern from the pre-Boston days, Beth Parkhurst, passed the general examinations in history for her doctorate at Brown University and has been awarded a Smithsonian Fellowship to study women in programming. Her first paper on the subject was presented at the 1985 meeting of the American Historical Association and will be published in *Daedalus*.

Gregory Welch, who took a year off from Harvard to work on the 1401, Cray, and manufacturing exhibits, has not only graduated Magna Cum Laude but also received the Shaw Travelling Fellowship. Greg will spend next year studying science and technology museums of Europe.

Bill Wisheart, who started as an intern on the collections after graduation from Boston College, has been accepted in the master's program in Computer and Information Sciences at Dartmouth College.

Survey of Museum Members

Almost 100 members replied to the first survey of the membership and it's my pleasure to publish its results. The respondents, from 25 different states, reflect the wide geographic distribution of members, with membership in 46 states, 9 European countries and Australia, Brazil, Canada, Japan, Indonesia and Israel. Before opening in downtown Boston, the ratio of local to non-local members was 2:3. Now it has reversed.

One-third of the respondents had visited the Museum three or more times and another one-third had never visited it. In the month of March, three percent of the visitors were members.

Preservation of computers and a liking for history were by far the most common reasons for becoming a member. Only 13% cited membership benefits as the reason for joining.

Respondents felt that the most important feature of the current membership plan is The Computer Museum Report. Thus, the Report is an important area where we can better serve members. The most interesting articles were on history, followed by anecdotes about artifacts, and articles about exhibits. The sense, in reading the individual comments, is that the Report should stand on its own. One written comment noted:

> I like historical articles both about the museum collections and computing in general. I am not overly fond of reports about events or exhibits that don't make sense unless you have been there.

Many respondents would like the Museum to undertake more outreach activities and include more member participation. By outreach, people mean both travelling exhibits, events, and making films available. These projects are all within the long range plan of the Museum. The first step is making films available. For example, Sperry videotaped the Presper Eckert talk and will add the historic ENIAC film to it. The purpose is to make this available for distribution by the Museum and by Sperry. The Museum is also beginning to build up a data base for member involvement with a redesign of the membership renewal form allowing you to indicate your wish to actively participate. Collecting activities is one area where members can be particularly helpful.

It's very rewarding to watch the network of Computer Museum alumni and members grow.

Gwen Bell
President

ENIAC
The Electronic Numerical Integrator And Computer

J. Presper Eckert

Dr. Presper Eckert (foreground), co-inventor of ENIAC (Electronic Numerical Integrator lend Computer; the world's first all-electronic digital computer, ENIAC weighed more than 30 tons and occupied approximately 15,000 square feet. Performing 5,000 additions or subtractions per second, ENIAC launched the computer industry as we know it today. Dr. Eckert currently serves as Vice President and Technical Advisor for Sperry Corporation.

Presper Eckert

If you consider the ENIAC as the starting point, the computer is forty years old. So, by the way, is the United Nations and I feel that we've done alot better than they have.

Talking about the ENIAC is like going back into the attic of my mind. And going into my real attic, I found a clipping from February 15, 1946. It says:

> "Mathematical brain enlarges man's horizons... A new epoch in the history of human thought began last night The scope and area in which man's brain can grasp, predict, control suddenly opened outward into the distance with revelation of secret construction during the war of a 30 ton mathematical brain that solves the unsolvable."

I read another article that said every time we turned the ENIAC on it dimmed the lights in West Philadelphia. This is pure fiction. We had it connected to a regulator in the generator room that was adequate for its power level.

Although the press notes that February 13th is when the machine was turned on, February 13 is an arbitrary date on which an announcement was made after some tests and trials. Other reporters stated that over 200 people worked on the project but the maximum group was 50 and the usual was about 30.

I met Dr. Mauchly at an advance management defense training course at the University of Pennsylvania. This course included about 30 people not in electrical engineering, of whom 16 were Phds. I was one of the lowest people on the totem pole; I was a graduate student and a teaching assistant. The meetings with Mauchly were along with a lot of very bright people. Mauchly and I had time to talk and we found that we both had a passion to build some kind of computing device. Mauchly had worked for the weather bureau and one of his motivations was to build a device that would help to predict the weather. The other thing that he had done as a professor of physics was build gas tube and neon lamp counters. I ran tests on them and found that they were not only slow but had very bad margins of safety, although they had the advantages of being cheaper than vacuum tubes overall.

Those responsible for the ENIAC project and present at the dedication appear in the group photo. I reported directly to Dr. John Brainerd and he reported to Dean Pender, a very wise man, who had been head of electrical engineering at M.I.T. before he came to be dean at the Moore School.

Colonel Gillen, the contract officer for the Army at Aberdeen Proving Ground, named the ENIAC, The Electronic Numerical Integrator And Computer. Originally, the name stopped with Integrator because we had only planned to use it for equations relating to the flight of a shell. As time went on, various people felt that the machine should be used for other problems. Colonel Gillen realized the uses would get more complicated so he added "And Computer" to the name. He said this was political protection. If the general accounting office said we went beyond the original bounds, we could point to the name and say it was in the proposal.

Second to me in the photo is General Barnes, head of the Ordnance Department. In 1943, I reported to the Roxboro draft board consisting of a French teacher and two men in the textile business. They thought everyone should be drafted, especially everyone in textiles where the men could be replaced with women. They also thought that anyone at the University could not possibly be doing anything for the war effort. I was doing something, but they couldn't be told what it was. They thought I was a new form of draft dodger. Each time before they called me, the French teacher would forewarn me and the university staff could be prepared. The doctors knew me quite well because I actually took the preliminary exam six or seven times. When the French teacher went on vacation, the other two men decided they would get me. I was called without advance notice and almost drafted. By this time, the University realized the importance of the project, contacted the Ordnapce Department and got a letter signed both by General Barnes, head of Ordnance of the US Army, and General Hersey, the head of selective service. The Roxboro draft board didn't harass me anymore.

After graduation from Penn, I worked at MIT's Radiation Laboratories building a special amplifier to test a switching device used in radar. The design of this amplifier, having a rise time of a tenth of a micro-second with a gain of over a thousand, gave me experience building high speed circuits. Then I had a project to measure a radar signal-travelling out and back-with an accuracy of 1 yard out of 100,000 in less than 9 nanoseconds. This was quite a problem because small, at the time, was 100 nanoseconds. I was instructed to do this with analog methods and decided in several weeks that they didn' know what they were talking about. I proposed a digital system using electric delay lines and another system using a mercury delay line that I invented for the purpose. Brit Chance my boss, let me try my idea ever though he didn't believe in it. I was working on that device using counter: and delay lines when the idea for building the ENIAC came along.

While I was at MIT, Mauchly dictated a memo about the design of a computer that his secretary typed with several carbon copies. The original was given to Dr. Brainerd to mimeograph and distribute. Brainerd apparently lost the paper before it was copied. Herman Goldstine asked for one of the carbon copies; but no one could find one. Fortunately Mauchly's secretary still had her shorthand notes so she reproduced them for Goldstine who used them to get interest at Aberdeen Proving Ground. This formed the basis for Aberdeen's request for a proposal for a machine from the Moore School. Dr. Brainerd who was in charge of getting projects for the School was now pleased with the idea. The three of us wrote a proposal and delivered it to Aberdeen on April 9th, 1943 (my 24th birthday). Dr. Brainerd and Dr. Goldstine presented the proposal to Colonel Gillen and Dr. Deterick, a civilian scientist. During the presentation, Mauchly and I, sitting in the next office, wrote the technical appendices backing up the proposal. When the group emerged, we asked, "What happened?" Goldstine said, "We gave them the story and Deterick said, I've got to go to another meeting but it seems pretty good and Simon agreed to give you the money." After we caught up on our sleep, we started to work right away even though the contract did not arrive for several months. Actually, the ENIAC project started on April 10, 1943.

Herman Goldstine was a great help getting us classified documents on counters built by RCA and NCR. These counters were used by the Ballistic Reseach Laboratory to measure the speed of shells as they left the guns. I built both circuits and by modifying the RCA counter arrived at a very stable design. We then decided on standards for the rest of the circuitry. I talked to the people at RCA's tube research laboratory in Harrison, NJ, about tubes and they shared the results of experiments where they got a much longer tube life by running them at lower voltages than consumer products. They also advised us to use standard tubes because they never got all the bugs out on special runs. They said it took 100,000 tubes before they were working right. I asked, "What do you do with the first 100,000." They said, "We sell them."

My education had prepared me to lead an engineering design team. At Penn Charter, I had a phenomenal math teacher who had put ten of us in a fast track studying solid trig, college algebra, differential calculus, and enough other material so that on testing at Penn I had completed the first year or so of engineering mathematics. Although I was admitted to MIT, my parents thought it would be better if I stayed closer to home and went to Penn. My father wanted me to study at the Wharton School of Finance, but I left after a short time because I hated it. I then went to the physics department but I couldn't get in because they were full and that's how I ended up in electrical engineering.

Carl Chambers, my advisor at the Moore School, was a mathematician, engineer, a former employee of RCA, and had a father who, at one time, was president of the American Actuarial Society. When Carl grew up his father wrote the exams and would give Carl the summer job of grading them if he could pass it. And he always could. So he was also a fine statistician. When I got a D in something like nineteenth century English novelists, I went to him. And he said, "That's ok. I did the same myself. In fact, I figured if I got too good a grade on something I didn't like, I was spending too much time on it. " Carl taught me the importance of very careful design. I did some circuit design for him and he always had me test it for all the variations possible. For the ENIAC, I implemented that idea with a vengeance. I didn't like the idea of ever making a failure by not doing it quite right; that can set progress back a step instead of forward. The Wright brothers were quite good in this way. They decided that Dr. Langley's equations that were available were probably not quite right even though his little plane had gone 4,000 feet powered by a steam engine. They decided to do something no one had done; build a wind tunnel first to test the wing designs. That's the real story behind Kitty Hawk. It's like the ENIAC: they didn't invent the engine or the idea of a wing or even the idea of an engine and a wing assembly. Another example is FM. In 1924, John Carson, who worked for Thornton Fry at Bell Labs, wrote a paper that worked out the equations for FM. He showed that in the normal ten kilocycle band width, FM would result in equally as much noise as AM. They also reasoned that building an FM detector was harder than AM and therefore they bypassed it. He was exactly right in all his mathematics, but of all the engineers who read it not one tried it. Then Major Armstrong came along and thought about it, saw that wide bands were available by then, and made FM work.

When we were building the ENIAC, the only other company I know who had experience building a machine with a large tube count was The Hammond Organ Company. They built about 1,000 Novachords, fully electronic musical instruments (synthesizers), each with 170 vacuum tubes. Eventually I bought an obsolete one for $100 from a men's drinking society. I refinished the cabinet, repaired some circuits, and replaced all 1,000 resistors. When I retired my machine five years ago, all the 144 tubes (operating at about 5 volts versus the specified 6.5) in the tone generating part were original. If the tubes gave any trouble then we lightly sandpapering the pins and they would work again; the surface of the pins deteriorate but nothing else.

At the time we were hassled by a number of scientists for relying on vacuum tubes. Enrico Fermi knew an electrical engineer named Willy Higginbottam working on a 150 vacuum tube counter at Los Alamos. Fermi assumed that the level of engineering perfection that we used was the same as Higginbottam who had a much simpler problem. We knew what we were up against and had to have long life from the tubes. Fermi, a great statistician and physicist, ran statistics on Higginbottam's counters and told Dr. John von Neumann that with the number of tubes in our machine it perhaps would only run 5 minutes without stopping. Since the ENIAC was 1,000 times faster than anything else, if it only worked 5 minutes out of every hour or so it would still be perhaps 100 times faster than any other machine. So we didn't worry about it.

Eckert - Mauchly patent 3,120,606

The big surprise to us was that programming would turn out to be so enormously difficult. That was a shock to everyone. At the beginning, every time the machine came up with a wrong answer, we blamed it on a machine failure. We soon learned to blame it on a programming error. We were incredibly careful in designing the machine. I took a slide rule and rechecked every circuit that was designed at least to a rough approximation. I found that I had to do this or the rules that we had set were not being stuck to. We realized that we had about 4,000 knobs on the machine. We started to wiggle a few test knobs and found that they could come loose. Someone suggested that we use hardened set screws with a hole in the switch shaft. We tested them and no knobs fell off. We "high potted all the wiring", that is we put it out on high voltage to check for weak spots in any insulation.

I had had experience with mice eating some forms of wire. So we got some mice, put them in a cage, starved them for a while, and then put in various kinds of wire that we were considering using. Sure enough, they loved some of the kinds of tubing we were planning to use. Then we used only wiring that passed the mouse test.

People often thought I was a nut because I was so fussy about standards, but I was only implementing the concept behind the famous statement of William Thompson, Lord Kelvin that Colonel Gillen had prominently hanging in his office. It stated, " When you measure what you are speaking about and express it in numbers, you know some things about it. But when you cannot measure it, express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge but you have scarcely in your thoughts advanced the stage of science."

The other principle that I went on, was that one ought to be liberal about new ideas but be conservative on their execution. In later years, we had a big sign in one of our labs and it said, "Principle or execution." What it meant was, when something didn't work was it due to the principle or to its execution.

I sometimes see articles that say John Mauchly was the idea man and Pres Eckert the implementer. This is a vast over simplification. In the beginning, John had built some counters and I had worked on the differential analyzer. I had learned to use a desk calculator, but I didn't know as much about them as John. Mauchly knew how desk calculators worked inside. I had never integrated an equation by difference calculus. John taught me alot about the problems to be solved on the ENIAC. I had designed a lot more circuits than John. When we started the ENIAC, John introduced me to his concepts for a subroutine in the machine. It was one of the big principles of the ENIAC. Using a straight line programming as in the Harvard Mark I, I figured the ENIAC would have had over a million tubes instead of 18,000. I was told later that Babbage may also have had the idea of subroutines. Our idea was to have nesting of subroutines. If Babbage had the idea outlined, then Aiken probably would have used subroutines on the Mark 1. We introduced Aiken to the idea of subroutines. What you can say is that John worked more on software and I worked more on hardware.

I think that I have enough evidence to show that I developed the idea of internal storage or the stored program. I proposed the idea to Mauchly. Arthur Burks, in an article in the *Annals of Computer History*, over and over again tries to compare the ENIAC to the Differential Analyzer. I think this is strange because I don't see any comparison. If there is a connection it is this: before Mauchly wroteup the ENIAC idea for Brainerd, we said the worst feature of the Differential Analyzer was the inaccuracy of the integrators. We had worked to achieve a one-hundredth of a percent accuracy from the previous tenth of a percent, but we decided we were at the top of an S curve. The machine might achieve a thousandth of a percent accuracy, but only with hard work and that was the end of the curve. Further room for improvement would have to be electronic. We thought that we might take the shafts that came into the integrator, put little pinwheels with stripes on them, look at them with photocells and get pulses out that told how the shafts were spinning around. These would be fed into some counters, multiply these counters, accumulate them in another counter, and then use another pinwheel on the output shaft and feed it back through a servomechanism to make it track the thing. This was a mechanical integrator whose guts were sort of a digital system. We decided that was crazy, if we were going to have all these pulses then we should shoot them directly and get rid of all the gears. Then we thought this counting pulses is crazy, to count a million you need a million, but in the binary code it only takes twenty pulses. And even in a decimal system that can be based from a punch card machine, it will only take 60 pulses. So we decided we would code numbers and shoot them around that way in our machine. And that's about the extent to which the differential analyzer influenced the ENIAC. Later Dr. Floyd Steel developed the Digital Differential Analyzer that had some popularity for some time.

The best way to dismiss Atanasoff is to say the machine really never worked and he didn't have a system. That's the big thing about an invention: it's that you have a whole system that works. De la Rue tried to build a lamp in 1820, Starr in 1845, Swan in 1880, and Edison built a whole system that related to the generator that was only developed five years before. Every one of Edison's ideas had been used before. Edison was a system's engineer and made it all work. The ENIAC was built as a system that has led directly to today's computers. I look back at the scenario and ask you to consider the following question: How would you like to see your life's work end up on a tenth of a square inch of silicon?

ENIAC's Birthday

On February 13, 1986, The Computer Museum celebrated ENIAC's 40th birthday with a champagne-and-cake gala complete with 1940's orchestra to remind revelers of the era which gave birth to the machine.

ENIAC's Big Birthday Bash was conceived and sponsored by Ann RoeHafer, Marketing Director for Bitstream, Inc. of Cambridge. Starting in 1985, Bitstream dubbed February 13th the beginning of the Digital Year with a special calendar. The 1986 edition of the calendar was given to each attendee.

Many aspects of the event paid tribute to ENIAC's significant impact on the evolution of the computer. The invitation to the Birthday Bash was designed and produced using computer generated graphics featuring the special effects of digital fonts. ENIAC received the most fantastic birthday card ever produced by a computer for a computer, thanks to the Fantastic Animation Machine. They created a computer generated animated video birthday greeting that was displayed throughout the evening, and has now been added to the Museum's permanent collection. The 20-second long piece required about 100 hours of compute time and would normally cost about $3000 per second of finished video- a labor of love to honor ENIAC and a show of support for The Computer Museum.

Presper Eckert and Kay Mauchly.

The birthday cake for 500 guests was fashioned after a Bitstream font spelling out E-N-I-A-C. A tastier type there will never be. Among the decorations was a ten by one foot digital sign in the Museum elevator carrying a continuous birthday message.

To insure many happy returns of the day, eight "ENIAC Enthusiasts", AT&T, International Typeface Corporation, NCR Corporation, Michael Parker, John Poppen, XRE Corporation, Herman Zapf, and Zenith Data Systems, each contributed$ 1Of or every year of ENIAC's age to support the event and subsequent Museum projects.

The tribute to ENIAC was really a tribute to those who had created her. What turned this celebration into a momentous occasion was the talk by her co-inventor, Dr. J. Presper Eckert. Dr. Eckert's appearance drew a full house with close to 500 guests seated and standing in the auditorium, and watching on closed circuit T.V. in the galleries.

Bitstream president, Michael Parker was Master of Ceremonies for the evening. He first presented Bernard Gordon, President of Analogic, to introduce Dr. Eckert. Bernard Gordon, who had worked for Eckert Mauchly Computer Company, introduced Dr. Eckert as, "the greatest engineer and role model I've ever known". In his opening remarks, Dr. Eckert expressed his regret that co- inventor John W. Mauchly was not there to share his stories or be a part of the celebration. However, he noted that Kay Mauchly Antonelli, Mauchly's widow, and a programmer on the ENIAC, was in attendance.

After Dr. Eckert's talk, a film composed of the only existing original footage of the ENIAC from 1946 was viewed. It was met by the audience with both awe and amusement, and was a perfect transition from the inspiring talk by Dr. Eckert to the official toast and cake cutting.

Michael Parker, back on the podium, offered the first toast to the =:41st digital year". The next toast "to the ENIAC" was given by Professor Maurice Wilkes, who studied the ENIAC before building the EDSAC. Kay Mauchly Antonelli toasted "the young ladies in the film", her fellow programmers. The closing toast by Dr. Eckert was in memory of John W. Mauchly.

The Sperry Corporation, which absorbed the Eckert Mauchly Computer Company, is producing a video tape of the lecture and the 1946 film clips for the Museum's collection.

The ENIAC birthday celebration drew the attention of the media nationwide: it was featured on the CBS Morning News, National Public Radio's *All Things Considered*, WNEV-TV's *SciTech Spot* and Cable News Network, and it was the subject of articles in TIME Magazine, the New York Times, the Boston Globe, the Boston Herald, and the Baltimore Sun. Also picked up by both the Associated Press and United Press International wire services, the story ran in over 50 newspapers across the country-from the Honolulu Advertiser in Hawaii to the Tribune in Scranton, Pennsylvania, from Investor's Daily in Los Angeles, California to the Daily Southern Economist in Chicago, Illinois!

Ushered into the world with special press conferences, the computer continues to hold public fascination with its growth from childhood to maturity.

Inn Roe-Hafer at the ENIAC function table, wearing the Eckert-Mauchly medallion.

VisiCalc and Software Arts:
Genesis To Exodus

Daniel Bricklin

Bob Frankston and Dan Bricklin.

Bob Frankston, who wrote the first spreadsheet has noted, "In the early part of the century, with the growth of telephones, experts said that everyone in the world would be a telephone operator by the nineteen fifties."

People laugh and say, "That's not true."

But it turns out, it is true. By 1950 everyone had a dial phone and knew how to "be an operator."

Similarly, a few years ago, Fortune Magazine and others were predicting that a million programmers would be needed by the nineteen eighties. Now with a million users of VisiCalc, two million users of 1-2-3, and with another million users of other spreadsheets, four million people are programming on spreadsheets alone. The prediction is true. People just don't know they are programmers.

Ben Rosen once said, "You communicate with VisiCalc in English." What he meant was that you communicate in a way that feels natural, but it isn't English. It feels natural, but it's also a programming language. FORTRAN was also quite natural for people who worked with formulas. Unfortunately FORTRAN, when used to do other kind of programming, is strange and unnatural. Different kinds of programming languages are needed for different applications. The programming language is not important, but it is important that people program. In fact, a single computer language restricts a person to one way of thinking. If people learn spreadsheets and word processing, then they are on their way to programming.

In the early seventies, it was predicted that the first personal computers would be used to control the watering of the lawn, store recipes and do other household tasks. Personal computers are still not used for these tasks, but are used, among other things, to run spreadsheets. In fact, when new personal computers are announced a spreadsheet program is part of the package.

GENESIS

Bob Franston and I met in late 1969 or early 1970 at MIT when we worked at TECH Square at the now defunct Multics Project. We learned about good code and products that either did not capture people's imaginations or were not marketed well. After MIT, I went to Digital where I was project leader of the WPS-8, their first commercial word processor, and I also worked on computerized typesetting. This gave me a lot of experience with screens and editing. Bob was writing BASIC on a consulting basis for a small company, ECD Corporation, that was making a machine called the MicroMind (may it rest in peace).

I wanted to start a small business with Bob, so I decided to go to Harvard Business School to learn the "secrets" of doing this. I spent a lot of time in Aldrich 108 with 80 other first year students. Sitting there in the spring of 1978, I came up with the idea of the electronic spreasheet. With all those other classmates to contend with the professor, there's lots of time for daydreaming, especially if you sit in the front row and the professor looks out above you. I invariably made simple addition mistakes in my homework. I wanted to do what the professor did on his blackboard: he would erase one number and Louis up in the back of the room would give him all the calculations that he had done all night to recalculate everything. I wanted to keep the calculations and just erase one number on my paper and have everything recalculated.

I had my little TI calculator that I would rest my hand on and imagine that it was a mouse-like object controlling a head up display similar to that of an airplane pilot. Then I could look ahead and say, "15% would be ok." Going with that metaphor I knew I wanted to move all kinds of things around. Getting more practical I thought it could be done on a micro like a Z80 with a screen and also a mouse. The first machine that I considered was the PDT from DEC, an LSI-11 based machine that didn't sell very well. Having heard about it, I learned that it would be on display at the an nual shareholders' meeting. By holding one share of stock, I was able to go and see it. They were not very agressive in trying to sell it to me. In the summer of 1978, I made a decision that when I graduated in 1979 I would pursue creating the electronic spreadsheet on DEC equipment and maybe sell it door-to- door on Route 128.

Before I left for the summer of 1978, I went to various professors for advice. I went to my finance professor, but he was busy and couldn't see me. I went to my production management professor and he said, "Well, that's really a good idea. People really use blackboards and they will use two roomsfull of them to set up the numbers for manufacturing production schedules. If you could do that electronically and connect them, then it would save time." But he was too busy to help me. Nevertheless I was encouraged by what he said. Then I went to an accounting professor. He told me, "Improving the human interface to any system would be good." Finally, I got to see my professor of finance. Looking up from his FORTRAN listings, he said, "There are many financial forecasting tools already. The idea will never sell. People have everything they need. But why don't you ask one of my students, Dan Fylstra, and he'll tell you why you can't sell personal computers to real estate agents to do their calculations." That's how I met the person who eventually pubshed VisiCalc.

Dan Fylstra, a second year business school student, was running a small home computer publishing company called Personal Software. He had just signed up a chess program called Microchess.

STARTING SOFTWARE ARTS

Frankston and I got together and decided we would work on an electronic spreadsheet in Bob's attic in Arlington, Mass.

One of the most difficult and important ideas was how to label where something was. It was clear to me that the simplest way was a grid coordinate system. Since people usually think in letters and numbers, I labelled the top with letters and put numbers down the side. My background had been on interpreters, on Multics I had implemented APL twice and VisiCalc is an interpreter. I used these skills and viewed VisiCalc as a programming language. Instead of the program being vertical, it was in two dimensions.

In the fall of 1978, we made a deal ,with Dan Fylstra that we would produce this electronic spreadsheet and he would publish it. We went to a Chinese restaurant out by Fresh Pond, Bob and I ordered without msg and Dan with it, and we got some very good terms. Two-thirds of the profits, 35.7% of the gross, went to us. In those days, Dan's company, Personal Software, was in an apartment in Allston.

Then sitting in a Kentucky Fried Fish place, Bob and I came up with the name of our company, Software Arts.

That fall, I prototyped the product in 200 lines of BASIC to simulate the electronic spreadsheet. I wanted to have a mouse, but the machine that Fylstra had that was available to use, the Apple II, didn't have one. The Apple did have game paddles to turn the dial and move things sideways. So I modified it to behave like a mouse and position things. Unfortunately the cursor moved too slowly using the paddles so I switched to the two arrow keys, one going right and one left, and used the space bar to go up and down. Then it ran much faster.

The final version of the original VisiCalc was written on the MULTICS system at MIT which we paid dearly for out of our pockets. We used timesharing at night. Bob would get up at 3 PM when I would get back from school and work until 6 or 7 in the morning. Since MIT took three months to bill, we also had a little float.

The name VisiCalc was conjured up at "Vies Egg on One" outside of Porter Square on Mass Ave. Early one morning, Frankston and Fylstra, desparate to come up with a name, were having breakfast and each claimed to have come up with the name. I claim they just looked at the menu that said "Vies" - and were inspired. Frankston threw together the first working version of VisiCalc in two to three weeks.

In January 1979, Fylstra went off to Apple and Atari to show them the product. Markulla at Apple said, "Hm, interesting checkbook program you market it yourself, we're not interested." Atari was very interested but their machine was not ready. The first VisiCalc ad appeared in the May 1979 issue of BYTE. That same month, TI's personal computer was delayed and Radio Shack had 50% of the PC market. The year before, Apple had shipped 20,000 systems and IBM sold 5,000 systems in the PC market.

We sent copies of VisiCalc to influential people, including an analyst at Morgan Stanley in New York, Ben Rosen. Ben liked his copy (the one that is now archived at the Museum) and wrote about it, saying, "Someday this may be the software tail that wags the hardware dog." And he was apparently right, because the spreadsheet partially made personal computers sell so well.

In June 1979, Software Arts moved from Bob's attic to a basement in Central Square, purchased our own Prime 550 timesharing system, and announced the product. Since I had just graduated and Bob was living like a student, we had simple requirements. We borrowed from friends and family to purchase the Prime. We didn't receive pay for about a year - and we used lots of float on Master- and Visacards.

"ALL HAIL VISICALC"

The first mention of VisiCalc in the New York Times appeared on the first page of the second section in a humorous article entitled, "A Layman's Trip into the Mega- mega Land of Computers." In giant letters, the author said, "All hail VisiCalc." He thought it was funny. We thought we could now say, New York Times says, "All hail VisiCalc."

In the winter of 1979, Software Arts moved again. Later, Julian Lange, a professor at Harvard, was hired and eventually became President. VisiCalc was then moved onto a large variety of machines. After a year, the original version was no longer sold, but replaced by an upgraded version.

We won Adam Osborne's White Elephant award for changing the course of industry. Our first cover shot was on the Boston Computer Society's Computer Update.

Then we had our first real competition. The Osborne I was announced with hardware and software bundled together to give the user no choices. Osborne had to have a spreadsheet and convinced someone to write SuperCaIc.

I received the Grace Murray Hopper award from the ACM, for something I had done under the age of 30. (Since I was no longer under 30, it made me feel good.)

Personal Software, riding on the wave of VisiCalc, published other things named "visi", like VisiTrend and VisiPlot, written by Mitch Kapor, their product manager for spreadsheets and other business products. Mitch met the people at Personal Software through Bob and me.

Bob and I appeared on the cover of Inc. Magazine, where, Software Arts was reviewed as a company for the first time. The rivalry with the publisher, Personal Software (eventually renamed VisiCorp) was mentioned.

VISI-WARS

Because of the rivalry with our publisher, Software Arts started to look toward scientific markets. TK!Solver was developed to do this and announced on the top of the John Hancock building in 1981. At this time, MicroFinance Inc., a little company down the street, changed its name to Lotus Development Corp.

Software Arts was growing so much that it needed more space and moved out to 128 in Wellesley Hills where an old warehouse space was renovated. We spent lots of resources developing products for new PC's that weren't successful, such as the DEC 350 and TI's personal computers. The company spread its resources very thin. We announced an Advanced VisiCalc on the Apple III, with everything everyone wanted, except we chose the wrong machine.

Lotus 1-2-3 and TK!Solver shipped within a few weeks of each other. I was the youngest distinguished lecturer at MIT until Steve Jobs gave his talk. At this time, VisiCalc was still the most popular program on the IBM PC and the Apple III.

In the spring of 1983, we realized that TK!Solver was not bringing in enough revenue to pay for our development projects. We decided Software Arts either needed additional funding or to be acquired.

Returning from the airport after midnight in September 1983, I was greeted by the information that I was being sued by VisiCorp. You can't sell a company when you are being sued! Almost everything stopped for months while the lawyers took depositions. After four days in court, it became clear that Software Arts would win the law suit a few years later. One day the next June, I was called back from the West Coast and we laid off half the employees to save money. That was about the most down day of my life. We finally hammered out an agreement with VisiCorp where we received all the rights to VisiCalc and a check for half a million dollars. It cost both sides a substantial amount of money and management time. Don't ever do it if you can help it.

Despite this, Software Arts came out with updated versions of VisiCalc and TK!Solver for the Macintosh, and Spotlight, a desktop manager program. But the company was underfinanced and we were still trying to sell it.

During this depressing time, Frankston and I turned up in Esquire's list of special people under 40. It was really getting very bad and we finally switched to a bankruptcy expert for a lawyer.

EXODUS

In the spring of 1985, I decided to go to Softcon and ran into Mitch Kapor, Chairman of Lotus, at the airline counter. He said, "Hey, Dan, how ya doin?"

> I said, "Lousy."
> "Not really."
> "Ya, lousy."

Then Mitch asked, "Do you want to talk?"

I went from my seat in steerage up to first class and Mitch and I talked about the Software Arts situation. Mitch said since Lotus was starting a scientific division they might be interested. A day or so later, Software Arts made a presentation to Lotus. Within 48 hours a letter of intent to purchase some of the assets was signed. Frankston moved over to Lotus and I was given an office.

Then Lotus decided they would no longer sell VisiCalc, and the press wrote nice things about it.

Now, I work at home in my office at my new company, Software Garden, named after the Garden city of Newton Massachusetts, where I live. My product is a "slide show" type of program that lets you create a simulation that tries to appear indistinguishable from a real running program. It's a real program for the creators of vaporware.

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Colors of Chaos

A Special Exhibit April 11-September 8, 1986

Oliver Strimpel

The pictures of Colors of Chaos are the result of using computer graphics as a tool for research in complex dynamics, a branch of mathematics and physics. The goal is to understand what happens to simple mathematical formulae when they are iterated.

The pictures are built up in the following way: each point is iterated using the mathematical formula under investigation. For example, if the formula is the trigonometrical function cosine, this corresponds to entering the number corresponding to a point in the picture into a calculator, and pressing the cosine button again and again. The point in the picture is then colored depending on what happens. In some of the pictures, the color shows how quickly the point "escapes" to infinity, leaving black those points that never escape. In others, the colors show where points end up under iteration, with the shades indicating how quickly they get there. Thus the colors represent the dynamics of the iteration.

Julia Sets and Mandelbrot Sets

Two types of picture can represent the iterative process. In the Julia set, the initial value of the complex number at the start of the iteration is varied over the plane. The parameters of the iteration are fixed. A point is in the set if it lies on the boundary of the points that become larger and larger as the iteration proceeds. Each set of parameters creates a whole different Julia set. One of the remarkable discoveries revealed in Robert Devaney's images is that the Julia set can change dramatically, even evaporate completely, for very small changes in the parameters of the iteration. The picture shown on the front cover is a still image from a film showing the dramatic change in the structure of the Julia set for the sine function as the parameter is varied. The black region shows points that have not escaped to infinity after 35 iterations, while the colored regions show escaped points. Red points tend to infinity the fastest, followed by points colored in orange, yellow, green, blue and violet.

The Mandelbrot set is an example of the second type of picture. Here, it is the value of the parameter that is varied over the plane and the initial value of the complex number is set to zero everywhere. Each formula being iterated has only one of these pictures. A point is a member of the set if it never escapes to infinity under iteration.

The first formula investigated by Benoit Mandelbrot in 1975 was simply the squaring of the complex number in which one iteration step consists of squaring the number and adding a constant. By varying this constant over the plane as the parameter, Mandelbrot discovered a cardioid shaped set with a hairy boundary-the Mandelbrot set. To the mathematicians' surprise, this shape appears to be universal in that it crops up, albeit somewhat modified in detail, when many other formulae are iterated. When the boundary of the Mandelbrot set is examined in fine detail, baroque swirls, spirals and tendrils appear, including some that lead to offshoots containing smaller replicas of the Mandelbrot set itself. It is this fascinating structure at the boundary of the Mandelbrot set that is vividly represented in the Colors of Chaos images that came from the Bremen group.

Julia sets and Mandelbrot sets can take a lot of computing. Firstly, each point of the picture has to be iterated separately (unless one uses a parallel machine), so the time taken to create an image is proportional to the total number of pixels computed. Secondly, the number of iteration steps required per point can be as high as several thousand. The closer to the boundary of the Mandelbrot or Julia set you go, the longer it takes a point to 'make up its mind' as to where it is really attracted. Each iteration step takes several floating point multiplies or the evaluation of a trigonometrical function. Robert Devaney has just used 72 hours of the Cray supercomputer at Digital Productions to make a new spectacular film showing Julia sets of cosine. It will be added to the video showing in the exhibit.

Images in the Colors of Chaos Exhibit

A series of twelve pictures shows Julia Sets and Mandelbrot Sets generated by the iteration of polynomial functions and ratios thereof by a team from the University of Bremen led by HeinzOtto Peitgen and Peter Richter.

A second series shows Julia sets of sine, cosine and the exponential function by Robert L. Devaney from the Department of Mathematics at Bost University.

Why do this?

Because it's there! The beauty of the images continues to spur along ever more detailed explorations of these newly discovered objects. But the computation of Julia sets and Mandelbrot sets can also be viewed as numerical experiments in complex dynamics. When combined with mathematical intuition, they uncover universal patterns and stimulate the progress of mathematics. They are also important in the new field of fractal geometry. Indeed the boundary of the Mandelbrot set is a fractal. Mandelbrot conjectures that it may have a fractal dimension of 2, which would mean that all offshoots would have to be connected to the mairr set and that the set's surface has barely been scratched. According to John H. Hubbard, Professor of mathematics, Cornell University, who was the first to make detailed computer images of the Mandelbrot, it is "the most complicated object in mathematics".

The iteration of complex functions also models the way many nonlinear natural systems evolve. Simple iterative laws can predict very complex, chaotic behaviour. Examples include the growth and decline of the population of a biological species, the motions of the planets, the changes in the weather and even the daily fluctuations of the stock market.

The Mandelbrot set, courtesy of Benoit Mandelbrot/IBM

EFurther Reading:
The Beauty of Fractals by H-O Peitgen and P. H. Richter, SpringerVerlag 1986

This new release contains approximately 75 color and 65 black and white illustrations, including many of the images on display in the exhibit. The text appeals to both layman and expert, and ranges from philosophical background to suggestions on how to generate your own fractal images. ($33.95 postpaid, $30.95 members)

The Fractal Geometry of Nature by Benoit B. Mandelbrot, W. H. Freeman, 1983 ($38.95 postpaid, $35.45 members)

Introduction to Chaotic Dynamical Systems by Robert L. Devaney, Benjamin Cummings, 1985 ($33.95 postpaid, $30.95 members)

The above books are available from The Computer Museum Store. Also available are a set of 8 color postcards of the Bremen images, including several on display in the exhibit ($4.00 + 1.00 postage).

Scientific American Computer Recreations column by A. K. Dewdney, August 1985 issue

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Return to List of Reports

Highlights from

The Computer Museum Report

Volume 17 ---- Fall 1986

Cover (220 K Bytes)

Contents of Highlights

The Early Model Personal Computer Contest

Oliver Strimpel

Every year the Fall issue of The Computer Museum Report features the Museum's collections. This issue constitutes a complete catalog of the Museum's collection of personal computer hardware as of July 1986. Collected artifacts not relating to personal computers will be listed next year. It follows a somewhat unusual collecting event - the Early Model Personal Computer Contest.

In the Spring of 1985, William Millard, then chairman of ComputerLand, toured the Museum with Pat McGovern, chairman of CW Communications, the world's largest publisher of computer trade magazines, and Gwen Bell, Museum President. Millard noticed gaps in our collection of personal computers and asked how the Museum could remedy the situation before the early machines disappeared. Bell, half in jest, suggested a contest to find the earliest personal computers. Millard took up the idea enthusiastically and offered ComputerLand's support for the collection. McGovern offered to publicize the event and the contest was born.

From October 1985 to March 1986 advertisements appeared in CW Communications' magazines all over the world. The heading ran-"Wanted: Old Thinker-toys". Phil Lemmons, editor-in-chief of Byte magazine also put out the call in Byte's tenth anniversary issue.

Offers flooded in - 320 in all from 13 countries. The early US commercial machines, topped by the Altair 8800's (13 offers) were well represented. There were also many offers of one-ofa-kind homebrew machines and single-board computers, mostly still in full working order. Perhaps the most bizarre offer came from Argentina-a manuscript dating from around 1800 containing a card punched with holes. Said to be from Marie Antoinette imprisoned in the Bastille, it contained a coded message to her supporters outside the prison. Overall the response from abroad was disappointing; the collection still needs foreign enrichment.

A total of 137 items were accepted. The remainder were declined to avoid excessive duplication, or because they did not really fall into the categories collected by the Museum. The donors shipped their items to us for the final judging by Stephen Wozniak, designer of the Apple II and co-founder of Apple Computer, David Bunnell, an early MITS employee and current publisher of PC World, and myself. It was on this occasion that Wozniak announced his intention to donate his personal collection of hardware and notebooks to the Museum. He also gave a public lecture to a packed house after the judging. We include his talk in this issue as the story behind the machine that epitomized the spectacular growth of personal computing-the Apple II.

In defining the personal computer, we excluded plastic or cardboard educational and toy kit 'computers' (such as CARDIAC, BRANIAC and GENIAC), as well as programmable calculators. We were impressed by machines in several categories. First, there were the highly original designs that had significant impact on the development of the technology. Don Lancaster's TV Typewriter and Lee Felsenstein's Visual Display Module paved the way to the keyboard and screen interface now universal on personal computers. They were each awarded a prize.

Next there were the early commercial products, bold design and packaging efforts. We awarded the first prize to the 1971 Kenbak-1, submitted by its creator John Blankenbaker. This small machine contained an eight-bit processor built up from medium-scale and small-scale integrated circuits, and qualified as the earliest personal computer known to the judges. Thi Truong's 1973 Micral was awarded a prize as the first commercially available microprocessorbased computer. The Scelbi-8B, the EPA Micro 68 and Cromemco Dazzler were given honorable mention in this category.

Some of these machines bore testimony to the extraordinary zeal of the early hobbyists. We gave a prize to Robert Pond's Altair 8800 and honorable mentions to a Southwest Technical Products 6800 and a TRS-80 Model 1 which came complete with every conceivable add-on board or peripheral and with extensive, well documented software collections. One Altair had even been time-shared!

Lastly there were the homebrew machines, some indicating that builders had gone to enormous lengths to make useful machines at low cost. The computer based on an RGS-008 kit gained honorable mention for completeness. There were machines that must have taken solid weeks of wirewrapping and soldering to assemble.

We received many offers of magazines, personal computer club newsletters and advertising literature. David Ahl, founder of Creative Computing magazine, sent us his large collection of personal computer periodicals. Volunteers from the Boston Computer Society are piecing together the offers to create complete periodical runs. The collections of literature and software will be listed in a later issue. The contest was a success - the Museum now has a very fine collection of personal computers, including some little known, but significant machines. This provides a unique historical record and a valuable resource for future exhibits.

The winners were flown to the Museum for "Personal Computer Pioneers Day" and presented with engraved silicon wafer medals. From left to right: John V. Blankenbaker (Kenbak-1), Robert Pond (Altair 8800 hobbyist), Lee Felsenstein (prototype VDM-1) and Thi T. Truqng (Micral). Don Lancaster (prototype TVT-1) was unable to attend the prize-giving.

Stephen Wozniak

The Making of an Engineer and a Computer

I was lucky as a kid because my Mom and Dad got me to do science fair projects, tell jokes, and have fun. I knew I'd get an electronics project for Christmas. I'd sneak down the night before and open up the packages (then close them up again). It was sort of like exploring a computer system without getting caught. In sixth grade my hero was Tom Swift who used his resourcefulness with technology to do good. The kids on my block wired house-to-house intercoms, helped by the local electronics store where we hung out. We got someone to give us a ton of telephone wire and we just walked down the block hammering it to the fences and jumping into people's yards and burying it in the ground. When you're kids you don't understand that, things are owned by others.

Mom gave me 35 cents a day for lunch. I didn't eat; I saved the money for a walky-talky. But I got nailed. The school had a lottery and I spent all the money on tickets. And I lost.

My father, an engineer, taught me how transistors work and got me interested in computers by giving me IEEE reports to read. This way I learned the basics of Boolean logic and built some adders/subtracters for science fair projects. By eighth grade I talked a company into giving me a few hundred transistors and diodes. I built some gates and figured out why they weren't working. It was a good head start.

By the time I got to high school, I was real fast on the slide rule and that helped me become the top math student. But when you're in math you don't take electronics, because you're in the college curriculum. Electronics was a shop course. Somehow a few people covered both. Neither the students nor the teachers in high school knew what a computer was and vacuum tube technology was still being taught. When I was a junior, a teacher said "we now have a computer and you can use it." I said, "Great ... what an opportunity." It was a little board that could be wired to create a relay. The teachers thought this was a computer!

Then, I had a teacher who recognized that I needed something beyond what the school could provide. He had a couple of friends at Sylvania and arranged for me to go down once a week to program computers. They gave me a FORTRAN manual and I thought it was the neatest thing in the world. Then one day, I saw *The Small Computer Handbook* on someone's desk. It described DEC's PDP-8. I read it from cover to cover learning about binary arithmetic, how ands and ors work, about registers, instruction sets, sequencing, and everything you needed to know to build a minicomputer. Later, when the growth of minicomputers started exploding, my favorite machine was Data General's NOVA. I started to design my own versions of it. Sometimes it would take 20 pages to design a floating point add. Then I tried to make the design smaller and smaller. Every time a company, like Fairchild, would come out with a new chip, I'd go back and re-design the NOVA using that chip. I'd make the design better and better using fewer chips. If I could have afforded building any of these machines, I would have stopped designing and learning. The reward was in improving a design.

In 1968, I headed off to the University of Colorado where I signed up for a computer class. This gave me the opportunity to sign up for computer time by using my student number. I didn't understand that computer time was charged for. As a kid I really didn't know about accounting principle sand I was still a kid. I was put on probation for computer abuse. I ran some programs that just printed scrap paper as fast as they could; others that ran every mathematical table that I could find - powers of two, inverse powers of two, and so on. Eventually my factorials would take more than a page and it would run 60 pages worth; that was what the CDC machine could do in under the minute that I was allowed as a student. It would punch out cards which I could submit again to make it start up exactly where it had stopped. I used 60 pages for each of six sets of tabulations three times a day for about a month. There were reams and reams stacked up in my dorm. I never thought that my professor would think that I was trying to get him because I was spending money that was unbudgeted.

That year I built my first video project, a device out of one transistor and some old radio parts that jammed TVs. I didn't try it out in my dorm because they knew me. I went to another dorm, sat in the TV room and started to jam the picture. A friend, in on the gag, went up to the TV, hit it, and I unjammed the picture. Each time I'd jam it, my friend would have to hit it harder and harder. Everyone understands that when an inanimate object doesn't work you just hit it. I discovered in that age of peace-loving anti-war college students that you could turn any group into animals just by jamming the TV set. One time I jammed it and someone said the TV repairman had been in and had said it was the antenna. So he held the antenna up in the air, and the set was perfect, but only for a couple of minutes, then it went bad again. The guy held it up higher. Same scenario. When it went bad, he stood up on a chair, and it worked, for awhile. Upon his tiptoes it worked; down on his heels it didn't work. On another occasion they discovered if you touched the set in a weird position -hand on set and leg on the chair-it worked. He said, "It's a grounding effect." And they watched the last half hour of Mission Impossible with a hand on the middle of the TV.

The computer class was very large. The professor would lecture to a quarter of the students and the rest would watch on TV monitors in another room. I built the TV jammer into a magic marker pen and took it to class. The class started and I jammed the TV. Three teaching assistants stood up, looked us over and I was scared. Then, before I paniced, someone picked up his books and started to leave early. He was near the worst jammed TV. As he got up the TV started to go in and out, until as he walked out the door it was perfect. I learned that whatever prank you do, make someone else get the credit.

My second year of college was in Cupertino. They had an IBM 360. I took some computer courses that gave me no credit at all, but they were what I wanted to take. I met a computer operator and I found that as an insider he had keys and passwords. We would go in late at night and run programs. By sliding a piece of paper over the official record on the console printer, we prevented our jobs from being recorded. One night the manager of the center came in at about 2 AM and found me alone in the computer room. I was scared because he didn't even know me. I said, "Larry went out for the pizza."

To pay for my third year of college, I went to work for a mini-computer company. It had a great machine with 64 terminals that could run FORTRAN and other programs. But the company was hit by the recession and went under. It was surprising for me to learn that people could invest two million dollars in a company and it couldn't make it.

In my spare time a friend and I built "The Cream Soda Computer", because we drank cream soda while we put it together from spare parts given to us by another company. The friend that helped me build it, introduced me to another friend, Steve Jobs. We were introduced because we both liked pranks and electronics.

In 1971, after a little stint on unemployment insurance, I went to Berkeley, one of a handful of colleges offering computer science, for my third year of college. I took a course on writing assemblers and wanted to learn computing, read every manual, try every code, and learn every language. Getting grades or going to classes was of secondary importance. One time I signed up for ten courses and only went to five. Steve Jobs, a freer spirit, went off to Reed College in Oregon, where he only attended the courses that he wanted to, not the ones that he was registered for. Reed was also free and let him hang around for two years.

One day at my parents house, I read an article characterized as "fiction" about these weird phone phreaks who drove around the country in vans with racks of equipment in their buses, plugging into communications networks. The author, Captain Crunch, philosophized that exploring the phone system would improve it for Ma Bell. I fell in love with this philosophy. I wanted to explore a system and a computer and I didn't care about free calls. Half way through the article, I called Steve Jobs up and started to read it to him. Suddenly I realized there were too many details in the article-frequencies of 700 hertz and 900 hertz. They gave too much information. It's too real. These are not things that a fiction writer can make up. My source for material at the time was the Stanford Linear Accelerator; I knew I could always get in there on the weekend. With those high end research types, the door was never locked. Steve and I went to the library and started to research the phone system. We discovered that the frequencies mentioned in the article were correct. Now we knew that we could build a box and make free phone calls all over the world. We even managed to meet the author of the article, Captain Crunch. I was so pure about the philosophy of the phone company as a system, that I paid for my phone calls home. Then, late at night, I'd call every country in the world. I showed it off. I told phone jokes. I sold blue boxes on the campus. I just wondered how far I could get. But I was still pure, I paid for everything I should pay for-I was just using unused wires. It was disappointing when I found out that the phone phreaks were not pure.

Blue Box, 1972

Inspired by the "phone phreak" hero Captain Crunch, Steve Jobs and Stephen Wozniak built their own tone generators to make free calls. Known as blue boxes, they were sold in the dormitories of the University of California at Berkeley where Wozniak was an undergraduate. The particular box shown here was demonstrated to a packed roomful of students performing the legendary experiment of calling around the world to a phone in the next room. The signals had to travel over such a great distance that there was sufficient delay for a person to walk over to the receiving phone to hear his own voice. Following this demonstration, Richard Prelinger bought the box for $120.

The box used a crystal oscillator and was switched on or off simply by inserting or removing the plug leading to the earpiece. The early boxes were equipped with a safety feature-a reed switch inside the housing operated by a magnet taped onto the outside of the box. Should the phone phreak be apprehended, the magnet could be removed quickly, whereupon the blue box would generate distorted off-frequency tones rendering it inoperable. "You tell them it's just a music box", said Wozniak. The taped-on magnet is visible on the bottom right side of the box.

Gift of Richard Prelinger

After that year at Berkeley I had to take another year off to work and earn enough money to go back to college. I got a job as an engineer at Hewlett Packard designing scientific calculators, an incredibly good product that bypassed slide rules. My career kept going up. While it's widely reported that I'm a college dropout, that's not true. It just took ten years until I had enough money to finish.

I started to get away from computers. The blue boxes had been fun. Then I heard about "Dial-a-Joke" and I started the first one in the San Francisco area. In those days you could not own your own answering machine, you had to rent it from the phone company. Two thousand calls a day came into my machine to hear a Polish joke. Then the Polish/American Congress Incorporated in Chicago twice threatened me with law suits. I said, "How about Italian jokes?" They said, "Fine with us." Twelve years later the organization gave me their national heritage award.

One night after work, I walked into a bowling alley and I saw the first Pong game. It blew me away. I wanted one and since I knew TV sets and digital logic, I designed my own. Around that time, Steve Jobs got a temporary job at Atari. He introduced me to some of those people, but I wouldn't leave such a good company as HP for Atari. HP really cared about its employees and I just didn't feel like leaving, for any reason. On the side, Steve and I got a job to design the game Breakout for Nolan Bushnell at Atari.

Then, one day, I went to see my old friend Captain Crunch who was in his basement on a teletype. He said, "I'm playing chess with someone at MIT." Then said, "Look I can log into all these computers." He was on the ARPANET. I said, "Wow, I've got to do this." The only way that I could afford it was to build a terminal. I designed a video terminal because the cheapest input output device was your own tv set. Later Captain Crunch was to go to prison for phone phreaking. The second time he got caught the judge said that if he ever did this again he would go to prison. He got the same judge the third time.

I had been out of the computer area for a while and I wasn't aware that the microprocessor had been introduced. A friend of mine, who had gone to MIT, called me up and said there was club starting up for people who had built terminals and things. Since I had just built a terminal and since I like to show off, I said, "Great, I've got to go to this meeting and show off my terminal." He didn't tell me it was a microcomputer club because if he had, I would have said, "I don't know anything." And I wouldn't have gone. I met a lot of interesting people there who were all talking about the new Altair Computer. Somehow everybody knew that some day they were going to own there own computer. I had decided back in high school in the sixties that I was going to own a personal computer - a 4K NOVA was what I really wanted. At the time, it was the cost of two Pintos and almost the cost of a home. This was a big thing to think: to have a computer instead of a home or a car. Now I discovered that there were people around who knew how to build affordable computers. And, I got back into the field by studying a microprocessor instruction set, the inner workings of the chip. I discovered a microprocessor was just like a minicomputer.

Over the next year, the club grew to five hundred members who met twice a week. We all worked for companies with mainframes-and submitted our decks of cards through the window and the computer priests would run the program. We'd try to crash the system because it wasn't ours. We were a group that had a purpose: the revolution of home computers. Byte Magazine started. In the beginning most home computers were sold as kits and you had to be a hobbyist who knew how to use a soldering iron and not be afraid to put one together. The members of our club were not high level managers; we ran around with holes in our jeans, and were a technical community who wanted their own computers. The club was based on sharing. Lee Felsenstein conducted our meetings. The first segment was called the mapping period. People offered information, material or discussed problems. For example, one of the members would ask, "Is there anyone here from AMI?" If no hands went up, he'd say, "I've got some chips to raffle off for the club." He gave the first Pong chip fox your home Pong game to members of the club before Atari got it. Then, in the random access groups, people matched offers and problems.

I still could not afford a computer so I started to think about building one for myself. A new company called MOS Technology introduced a new microprocessor, the 8-bit 6502 costing $400. It was the finest microprocessor yet and they sold it over-the-counter at a show in San Francisco for $20-a very unique marketing step. A lot of folks from the club bought one and that night at the Homebrew Computer Club meeting it was a big topic.

A company called Sphere stopped by our club meeting with a 16-bit minicomputer hooked up to a color monitor that spun a color clock around. To see a computer doing color on a video screen was beyond our imaginations. It was shocking. This was at the time that Microsoft BASIC was only available on paper tape for input via Teletype terminals. The first two attempts at color for personal computing came from the club: the Dazzler, built by Cromemco, and the Apple II computer.

Although I had a FORTRAN and ALGOL background, I saw that BASIC was going to be the language for personal computers. Within two months I wrote a BASIC that would run on the 6502. I wrote a simulator in ALGOL to see that it would work. I had to assemble the code by hand, because I didn't have a computer to work on. Once it was done, I put together what became known as the Apple 1. I worked hard and late to get it done before January when I was getting married. In late November 1975, I demonstrated the Apple 1 computer running BASIC. All it could do was a tab and a print.

I went to Hewlett Packard with the design and the costs and suggested that they manufacture and sell it for $800. My manager was intrigued with a machine that could run BASIC and have 4K of RAM that would sell for about the same price as HP's top-end calculators. He was especially interested since HP's desk-top machine sold for $5-8,000. He said no to the project in the end. But this took weeks.

One time when I was showing off the computer at the club, Steve Jobs came along and said, " Why don't we sell it?" I was passing out a lot of schematics and literature because a lot of people wanted to build one. Steve said, "Let's just make the PC board for $20 each and sell them at the club for $40." We figured we'd have to sell 50 to get our money back and we didn't think we could sell that many. Steve said, "We might not sell 50, but at least we'll have a company." Steve's motivation was to be like Nolan Bushnell. I was telling Steve about everything that microprocessors would do one day, which was everything that minis did. I bought a microprocessor for $20, a keyboard for $60, a few transformers for about $10 each, and picked up the integrated circuits from the lab stock at HP. The company has a written rule that any engineer can take chips from lab stock without cost for a project of their own design if their supervisor approves. The company feeds that one learns by doing, and that the lowest level of management can decide.

One day Steve called me up at HP and said, "Guess what." "What?" "I got an order for $50,000." That was the biggest shock of the Apple experience. Steve had gone down to the Byte Shop where they bought Altairs as kits, wired them in the backroom, and sold them as personal computers. Steve discovered that it would only cost $13 to insert all the chips on our board. The Byte Shop placed an order for 100 computers at $500 each and we had to purchase the parts. To come up with the money, I sold my HP- 65 calculator for $500. However I knew we were coming out with the HP-67 the next month and my employee price would be $37, so I didn't take much risk. I still had my HP job as well. Steve went to the component suppliers and by showing the order asked for 30 days net credit. The chips were stocked in a closet at the company making the board. When the chips came out of the closet the 30 days started. When the pc boards came off the line, they would be stuffed with the chips and then put on the wave soldering machine. In two days 25 boards were complete and we drove over and took them to Steve's garage. We'd plug in the keyboard and the TV and some transformers and test the boards with the oscilloscopes to see if they would work. On the weekends we would sit down with the ones that didn't work, and usually found the problem in bent pins. Then we would deliver them to the local store and get paid. It was a ten day cycle. It's amazing what you can do when you have one level of management.

The Apple 1 design had few chips and was optimized for one board. The biggest decision was memory; the first 4K dynamic RAMS were about to come out. One principle that Iliad was "the fewer chips the better". After a discussion about chip size and number of pins, I decided that I would go for optimizing board size. When the 4K dynamic RAMS came out I could do in 4 chips what I used to do in 32. In 1975 several styles of 4K dynamic RAMS came out; the first set were from AMI and the second from Intel. The Apple 1 had the right RAM, a 16 pin Intel chip that led to a 16K RAM.

> Apple 1, 1975
>
> In designing the Apple 1, Wozniak squeezed as many functions as he could onto a single PC board. The upper two rows of integrated circuits constitute the video terminal he designed in 1974 to access mainframes remotely; it contains its own memory consisting of 7 1K dynamic shift registers and displays characters in a 5 by 7 matrix, with 40 characters per line, 24 lines per page and automatic scrolling. It interfaces to an ASCII encoded keyboard which is plugged into the empty socket at location B4. The video output and low voltage AC power sockets are at the top left corner. The lower two rows are the computer, shown in schematic form on the cover. The 6502 microprocessor is in the white package on the bottom row towards the left; the 16 chips on the right (A,B11- 18) are 4K dynamic RAM's; 2 PROM's, containing the 256 byte resident system monitor program, are at the bottom left corner. The memory could be expanded to 65K via the edge connector on the right.
>
> Gift of Dysan Corporation

After I had my legal release for the machine and was selling Apple 1s, HP had a project called Capricorn - doing everything that I had just done. I went to the new lab manager and I said I'd do anything to work on the personal computer and he turned me down.

Steve and I went to Atari and asked if they would like it. They said, "No, the home video market is going to be very large." They were so friendly to us, that they let us buy chips for the Apple 1 right out of their warehouse. We went down to Commodore and talked to Chuck Peddle who was about to do the Pet Computer. Steve thought we might get a few hundred thousand dollars but they only offered us employment. All in all about 200 Apple 1's were sold out of the garage.

A few months later, I started to think about color. I made sure that the Apple 1 worked at the right speed so that color could be added. Things began to coalesce. I realized that I could combine video screen memory and processor memory and save chips. The Apple II design started to emerge. It would be twice as fast, do twice as many things, and have tons of memory. In the first days, I designed the Apple II to work with both 4 and 16K RAMS (because the 16K chips were still very expensive). There was an issue of slots for extra cards. How much do they matter? The only argument over the Apple II design was that Steve Jobs wanted two slots and I wanted eight because I was a little leery about locking into too little. So I sat down with Steve and said, "OK, I don't want the company." And we had eight slots. That was the end of it.

I decided to write the Atari game Breakout on a microprocessor, in BASIC not in hardware. So I wrote some commands in BASIC to put color dots on the screen and to make sounds come over a little speaker. It was shocking to me how much you could do in software and still run so much faster than hardware.

Originally Apple had three partners: Steve and I each had 45% and Ron Wayne, who helped with the manual, had 10%. Ron sold his 10% to us for $800. The Apple II looked like an outstanding product that could sell 1,000 a month. We thought we had hit the big one. The problem was that we didn't know how to build a thousand of something that cost $250 each. Where would we get $250,000 worth of credit? We had to look for money. People would come by the garage and ask, "What's the market?" I'd say, "A million." They'd say, "What makes you say that?" And I'd have too rational an answer: "There's a million ham radio operators and more people are getting into computers." There's no way that answer could be wrong but they weren't the right words. We got directed to Mike Markkula, who had wanted to build computers in the home for quite a while. He had left Intel with a lot of stock options and he was still young. He started developing a business plan and joined us as a third and equal partner. For a while I didn't want to leave Hewlett Packard. Then a friend said to me, "Steve, you can start this company, manage it and get rich. Or, Steve, you can start this company, stay an engineer all your life and get rich." I realized that I could still sit down and write code and build things, and that the company was just a way to make money. We hired a President who could get things done. Steve had a friend at Atari who could design switching power supplies which required less cooling than the regular type. Our phony reason for needing this was our belief that no computer should have a fan.

We started producing Apple II's. This was the first computer that you could take out of the box, plug in, read only a little bit and start typing, "playing" BASIC. It was the first computer to be in a plastic case; it was the first computer to come with video as standard; it was the first to build BASIC in ROM; it was the first low cost computer to come fully assembled; it was the first to have paddles and sound. Fortunately it had a lot of memory slots. While the world only wanted 4K bytes that year for anything, they thought maybe 8 sometime, but 48K bytes would never be needed. In the beginning, The Commodore, Radio Shack and Apple machines all sold in about equal numbers. Then, 8K programs started to come out and, in 1978, the first spreadsheet and floppy discs came out. Both needed more than 8K of RAM. The Apple was the one of the three that had expandable memory and could support spreadsheet or floppy control software. With Visicalc computers had a different flavor: now you could walk into a store and buy a computer with a solution. Our dreams of people controlling garage doors and keeping recipes were of much less importance.

A lot of things happened at Apple because one of the top managers had a pet project. One of Mike Markkula's pet ideas was that recipes and keeping track of the check-book were going to be principle uses. So he had Randy Wigginton (who was to write MacWrite in the future) write a check-book program in BASIC. Two things came out of that: a floating point BASIC to make it easier to write money handling programs, and the addition of a floppy disc to make the machine fast. The current practice had been to use cassette tapes that took three minutes to load a program after which you could add the data for two checks, and then download, which took another several minutes. We started to work on both projects. The floppy disc controllers at the time used about 50 chips. I had figured out a design with five chips and thought that I must be leaving important things out. But after a lot of analysis of other designs, I found that mine did even more. So I knew that I was onto a good winner: real fast, real small (based on the new 5 and a half inch disc from Shugart), and real cheap. From that time, Apple took off. We were backlogged for four months of orders and the path had been set.

We premiered the floppy disc at the first National Computer Conference in Dallas that allowed microcomputers to be shown. This completed the initial development of the Apple II. I don't remember much about the show, but the hotel was the first one that I stayed in that had movies you could dial in your room. I had designed one of these systems while I was at Hewlett Packard and I knew that it has to send your room number down to a computer. Travelling with our tools, we opened up the box and saw a bunch of switches. I just toggled in a different code on the switches and didn't get billed for the movies. Randy Wigginton and I looked at the touchtone phone with different numbers for room service and so on. 'We took it apart and rewired the keypad to go vertically instead of horizontally.

QUESTIONS

There are some things that are inevitable in history and other things that depend on a unique individual. How do you feel about your role?
Almost everything would have happened about the same time. It turns out that my whole life was directed to one kind of computer design and when the window occurred, I was there. It was great luck for me.

What is it like to have to use an assumed name to go to college and to be a hero?
I used an assumed name and went back to Berkeley in 1981-2 for a full year. And I got away with it, because I wasn't known quite that well then. It was strange to read about myself. I couldn't understand why people would want to come up and shake my hand. Then I met Ted Turner who was my hero for challenging the networks and I asked him for his autograph. I now understand that we all want to have heros.

How do you feel about the Macintosh?
I love my Macintosh. I brought it on the trip. I dropped it in the San Francisco airport but it lived.

What's your relationship with Apple?
Since the computer keeps track of the employee benefits, I make sure that I get the minimal salary. I travel on their behalf, consult with them, and think its a great company.

What is your new company doing?
CL 9 is working on remote control devices for the home. It's not going to be a huge company but it's fun. Right now two engineers are working together in an environment where we can do great things.

Micral,
by R2E, 1973

The Micral is the earliest commercial non-kit computer based on a microprocessor. The founder and president of R2E (Realisations Etudes Electroniques), Thi T. Truong, created the Micral as a replacement for minicomputers in applications where high performance was not required. He perceived a big gap between minicomputers, such as the DEC PDP-8, on the one hand, and a wired logic system on the other. As soon as the Intel 8008 microprocessor was introduced, he decided to build a computer to fill this gap.

By May 1973, barely six months after the Intel 8008 became available, Truong together with engineers Francois Gernelle and Ben Chetrite, had the Micral designed and built. It had some remarkable similarities to later personal computers such as a bus system and slots for expansion. The basic original model had 256 bytes of RAM, and could be expanded to 2K with ROMS and PROMS. It was capable of directly addressing 16K, and boards to expand the memory beyond 2K soon became available. The Micral had a real-time clock, eight levels of interrupt priority and automatic enabling and disabling. The CPU, memory, input/output interfaces and fast peripheral controllers all plugged into the Pluribus - a 60-bit single data bus. There were 52 instructions, oriented towards process-control and data transmission applications. Instruction times ranged from 7.5 to 27.5 microseconds. The Micral had an assembler and an operating system which supported a teletype and cassette recorder connected to the Pluribus. The machine evolved rapidly, with later models offering more RAM, floppy discs, hard discs and a range of standard software.

Thi T. Truong, speaking at the Museum after receiving his prize.

The Micral's low cost of $1950 and bus architecture attracted great interest. By 1974, only six months after the Micral's debut, 500 had been sold; 2000 were sold over the next two years. However, following an unsuccessful attempt to penetrate the US market, Truong could no longer finance the growth 9f his business. In 1979 he sold Micral to the major French computer maker Bull who currently produce IBM PC-compatible Bull-Micrals.

Micral advertising for the National Computer Conference Exhibition, Chicago May 1974.

The first Micrals were sold to industry for process control and to the French government to help collect demographic information in France's African colonies. It was therefore supplied with a strong protective metal cabinet.

Gift of Thi T. Truong

The Micral's CPU board. The use of a microprocessor earned the Micral the name 'microcomputer', used for the first time in print in the June 21 1973 issue of Electronics magazine.

Kenbak-1, by Kenbak Corp., 1971

Kenbak-1, by Kenbak Corp., 1971

The Kenbak-1 was awarded first prize in the Museum's Early Model Personal Computer Contest as the earliest personal computer. It was presented to the Museum by its designer and builder, John V. Blankenbaker.

Blankenbaker became interested in computing while at college. In 1951, during his junior year, he got a job at the National Bureau of Standards where he came into contact with the SEAC (Standards Eastern Automatic Computer) project. The following year Hughes Aircraft charged him with the considerable task of building, from scratch, an arithmetic unit based on binary-coded decimal numbers. At that time, flip-flops cost $500 each. He struggled to design the machine with the absolute minimum number of flip-flops and even came up with a design that would use only one. Though such a machine would take a long time to get through even one clock cycle, it could emulate any other computer. Blankenbaker was so taken by this single flip-flop design that in 1955 he tried to patent it. Though he was unsuccessful, the idea of a $500 computer had been firmly planted in his mind.

In 1970 Blankenbaker actually set out to build a small computer. His fixation upon a selling price of $500 meant that he had to keep the cost of parts down to about $150. He decided that speed was not important and that the only input/output within the price constraint were lights and switches. However he did cut a slot in the front panel in the hope that one day punched card input could be added.

He could only afford the tooling costs for the printed circuit board. Everything else, including the cabinet, lights, switches and logic circuits had to be made from standard parts. He decided that the machine would be byte-oriented, and that 256 bytes would be a good choice of memory size. This allowed a single byte to store a complete address. In any case, manual loading would take too long with any more memory than that. Two 1K-bit MOS shift registers were used.

Kenbak's most successful advertisement, Scientific American, September 1971

Since microprocessors had not been introduced yet, Blankenbaker built his processor from standard medium-scale and small-scale integrated circuits. It operated on 8-bit words, one bit at a time. The 1 MHz clock coupled with a serial memory organization gave the Kenbak an effective speed of 1000 instructions per second. Altogether the machine used 130 integrated circuits, all mounted on a single board.

In Spring 1971, a working prototype was shown to a convention of mathematics teachers. Blankenbaker even managed to demonstrate a three-dimensional tic-tac- toe program that just squeezed into the 256 bytes. Complete documentation, programming manual and. exercises suitable for school laboratories were published.

The Kenbak Corporation was formed, and the computer was marketed through advertisements and direct mail. From the start, the machine was billed mole as an educational tool rather than as a full-blown machine for executing applications programs. The marketing was accordingly focused on schools as a low cost way of introducing hands-on computing to students.

Although small computers eventually found their way into the classroom in large numbers, the Kenbak never caught on. The alternatives at the time, timeshared minicomputers and programmable calculators, were beyond the reach of school budgets. Teachers were not yet attuned to the idea that an electronic computer might be affordable, and those that wanted one often took a long time to secure the funds. Only 40 machines were sold to schools and a dozen to individuals over two years. In 1973, the Kenbak Corporation closed its doors. Blankenbaker moved on to use his creative engineering talents to build the first production LISP workstation for the newly formed Symbolics Inc.

Altair 8800 by MITS 1975

The Altair is widely thought of as the first personal computer. Indeed, the Altair's creator, Ed Roberts, founder and president of MITS (Micro Instrumentation and Telemetry Systems), coined the term. Distinguishing PC's from hobby machines, demonstration machines, industrial machines and development systems, his view was that PC's had to be used for applications typically run on a minicomputer or larger computer. The PC also had to be affordable, easily interfaced with other devices and feature a conventional console with a keyboard, CRT or something similar. It should have an operating system and mass storage; paper tape was acceptable. A PC should have a reasonably large memory. MITS used 64K because that was what the 8080 could directly address. Lastly, he stipulated that a good number of people had actually used the machine as a computer that was personal!

Ed Roberts

In thinking about what sort of device to build, Roberts considered the DEC PDP-8 as a prototype. However, the machine that had the greatest impact on him was the Hewlett Packard 9100, introduced in 1968. It had a CRT, keyboard, magnetic storage for programs and data, and a printer. It could even drive a plotter. But it was not a personal computer by Roberts' definition-it was expensive ($6000), did not have a real programming language and only had a small memory.

In 1971, MITS introduced the 816, a kind of programmable calculator. Several thousand were sold, mainly for accounting applications and as controllers. In the same period, a company called Prolog built industrial processors based on the Intel 4004, 4040 and 8008. Intel built the Intellect series of machines between 1971 and 1973. The TV Typewriter was also noticed by MITS, as were several logic demonstration devices and an 8008-based machine, the Mark-8, introduced in Radio Electronics in 1974.

In 1972 MITS made a terminal system that could be interfaced to time-shared computers. "In 1973 and 1974 we started design work at MITS with 4004, 4040 and 8008 processors and didn't feel that they were powerful enough to do the sort of things you normally expect a minicomputer to do", Roberts said. "When we found out about the Intel 8080 in late 1973, we started design on the Altair, which was finished in the summer of 1974."

Ed Roberts and Bill Yates designed the Altair with an open 100-line bus structure. Though originally known as the Altair bus, it was adopted for so many other machines that it later came to be called the S-100 bus (S for Standard). The first machines were shipped with only two of the 18 available slots filled with the CPU board and the 256 byte memory board. Programs had to be entered in machine code via the switches on the front panel. During the next few months, MITS as well as many third parties, came out with expansion boards to provide more memory (up to a maximum of 64K) and interfaces for input-output devices and storage media. One of the first boards was a 4K memory board, big enough to hold a 4K BASIC interpreter specially written for the Altair by Bill Gates and Paul Allen.

The original Altair sold without the case for $297, $395 with the case-an order of magnitude less than the cost of the PDP- 8. Though initially offered as a kit, the first units were sold as assembly units since the kit manuals were not completed.

The demand for the machine exceeded even MITS's wildest expectations. More machines were sold in the first day than the company expected to sell during the entire lifetime of the product. Roberts likes to point out how MITS increased the installed base of general computers by 1% each month for a period between 1975 and 1976. There was a huge pent- up demand for a computer with the kind of power offered by the Altair. Most of the machines were purchased by electronics hobbyists who simply wanted to have a machine of their own. They tinkered with and modified their computers. However the machine was not really powerful enough or equipped with enough software to enable it do useful work conveniently. It was used to control various processes-some industrial, some recreational. One of the first customers used his Altair to control his model railway.

The company was sold to Pertec in 1977 for 6 million dollars. Faced with stiff emerging competition from companies such as Processor Technology, IMSAI, Commodore and Apple, Pertec was unable to retain market share, and the Altair went out of production in 1978.

MITS and the Altair played a central role in the development of the US personal computer market. They pioneered a whole marketing style-computer shows, computer retailing, computer company magazines, user groups and numerous add-on hardware and software options.

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Highlights from

The Computer Museum Report

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Contents of Highlights

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Jettons. During the Renaissance, Europeans counted with Roman numerals. But even for people accustomed to using them, Roman numerals are not easy to calculate mentally, and paper and pens were hard to come by. Merchants used copper tokens called "jettons" to calculate prices.

The jettons were moved about on lines. Merchants could draw the lines on the ground or scratch them on a table. The lines represented different values of ten; ones, tens, hundreds, and so on. For intermediate values, like five or fifty, a space was left between the lines. In the same way that you know immediately what is meant by $1.98, the Renaissance buyer and seller immediately recognized the price by the position of the jettons on the lines.

Until 1700, calculating tokens were common in Europe. The tokens usually derived their name from moving them about the lines while calculating; the word "jettons" comes from the French verb "jeter" meaning "to throw." Adept calculators must have made their jettons fly across their counting boards! By the mid- 18th century both the Roman numeral system and jettons had disappeared from everyday use.

A competition between the Hindu-Arabic form of mental and paper arithmetic that we use today and Roman numeral figuring using jettons. The dismay of the jetton user shows graphically who is winning. The mid-18th century saw the widespread availability of paper, of printing, and the use of the Hindu-Arabic number system with the simultaneous decline of the use of Roman numerals and their computation with jettons.

These copper jettons are from 14th-century Italy. The designs on jettons were often symbols of different trades or coats of arms. Depending upon the wealth of the owner, jettons were produced in metals varying from copper to gold but they were not coins. In fact, a new set of jettons was a customary New Year's gift. The old set would then be thrown in a river, symbolically clearing last year's accounts.

Remnants of jettons remain with us today. Merchants had boards in their shops on which to toss their jettons to calculate bills; stores today still have "counters." From the collection of Gwen and Gordon Bell.

Abacus. Most eastern countries used an abacus of some sort. It emerged from the Middle East sometime after 500 A.D. and was based on a system in which pebbles were moved around on the ground to represent numbers and perform calculations. (The word abacus is from the Semitic word "abaq," meaning dust.) The Chinese developed a version that they called a suapan. The Japanese modified the suapan and called it a soroban. An abacus is rather similar to jettons. The difference is that instead of scratching lines and carrying loose jettons, the tokens were strung on wires, and then framed. The abacus became the indispensible calculator for eastern merchants. It was easy to carry. And for the skilled user, it is very fast. People who use an abacus learn to recognize numbers simply by looking at the position of the beads.

The Japanese "soroban" has sharp edges to its beads and only one bead in heaven and four beads in earth to make operations faster. From the collection of the Peabody Museum of Salem.

The soroban has not declined in use since the advent of its rivals the calculator and computer. In some banks, the daily computerized totals are double checked with a soroban. In learning the soroban, students learn to visualize the position of numbers. The soroban champion, Ms. Nishida, can add eight ten-digit numbers in less than ten seconds simply by visualizing the position of the beads in her head. In fact, the Japanese claim that learning the use of the soroban can increase a students I.Q.

The Chinese "suapan," or "counting tray," has round beads and is divided into two sections. The top section is called heaven and contains two beads, each worth five units. The bottom section is called earth and contains five beads, each worth one unit. The suapan was used in China by the 1300s, and it became widely popular in 1593 when the mathematician Chen Ta-wei published a book on abacus computation. The abacus is still such an important part of Chinese culture that May 10 is celebrated as National Abacus Day. From the collection of Gwen and Gordon Bell.

Scientists' Instruments The year 1670 marked the first recorded appearance of Halley's Comet. A seventeenth- century astronomer bent on knowing the heavens and such predictions as the recurrence of the comet, faced very complicated calculations. He often needed to multiply vast numbers to describe the motions of the planets and the stars.

Astronomers were greatly aided by the Hindu-Arabic numeral system introduced to Europe around the fifteenth century. This number system made the sophisticated arithmetic of science possible. In addition, a wide variety of calculating tools were developed that stored information including the development of printing and the production of books of tables. These tools saved the scientist time and increased the accuracy of his calculations.

Napier's Bones were invented in 1617 , when John Napier, a Scottish baron, published a book describing the device. Within a few years, it had spread throughout Europe and as far as China. Napier's Bones (so-called because they were often made of bone) were rods with multiplications tables on them. At the time, educated people often knew their multiplication tables only as far as 5 x 5.

The concept of the pocket book of tables started with the development of printing itself. (1) The 1683 table of trigonometric values was useful to navigators, surveyors, astronomers, mathematicians and architects. Such tables eliminated the need to constantly calculate the trigonometric values of numbers. However, few tables were free from mistakes, and corrections were often put in by hand. From the collection of Gwen and Gordon Bell. (2) This set of logarithms tables was compiled in 1839 in England by The Society for the Diffusion of Useful Knowledge. To multiply two large numbers an astronomer would look up the numbers in the table, and add the listed logarithm values. The number in the tables that corresponded to the sum of the logarithms was the answer to the original multiplication problem. From the collection of the IBM Corporation. (3) Easily carried in a shirt pocket, Thompson and Thomas's Electrical Tables and Memoranda, published in London in 1898, was a handy reference for the electrical engineer wherever he went. From the collection of Gwen and Gordon Bell.

These calculations were performed by Johannes Kepher for his Ephermerides, dedicated to Napier for his invention of Logarithms. These were typical of the long hand arithmetic used to numerically describe the movements in the heavens.

The 18th century scientist/scholar/gentleman had a number of elegant devices that could be carried in the pocket and be the mark of a learned man. These include such items as
(1) A pocket set of drawing instruments in an elegant shagreen and silver case would have been useful in producing a map of the heavens. From the collection of Gwen and Gordon Bell.
(2) A portable sun dial, made in Augsburg, Germany, during the middle of the 18th century, was a precursor to the pocket watch, for telling the time of day. From the David Eugene Smith Collection, Rare Book and Manuscript Library, Columbia University.
(3) An Arab astrolabe that could be used to determine the position of the stars and sun on any day of the year. The spikes on the top piece of brass represent the major stars and could be turned about the brass plate below it. The etching on the plate is a map of the heavens. Different plates are used depending upon the user's latitude. From the David Eugene Smith Collection, Rare Book and Manuscript Library, Columbia University.
(4) Napier's Bones in its secure case. From the collection of Gwen and Gordon Bell.

Napier's Bones were used for multiplication, division, and square and cube root problems. It was simple to arrange the rods to solve complicated problems. In the Museum's exhibit visitors utilize a super-sized model of the device.

Digital Adders. Most mechanical adders use gears to "count." As you enter a number the machine "counts" the number of gear teeth that you advance. Calculating by counting is called digital calculation. The idea of using a stylus to advance gears to perform addition dates to 1642, when the French mathematician Blaise Pascal (1623- 1662) invented a calculator called the Pascaline. Many mechanical calculators built for the pocket operated on similar principles. The gears only went in one direction and the machines only held one register. Subtraction was carried out by 9's complement arithmetic, and multiplication by repeated addition. These were able to be widely produced for a very low cost and became the mechanical helper for many people.

The Webb Adder was patented in the United States in 1869. Any two-digit number could be directly entered on the large gear with a stylus. When the large gear had made one complete revolution it advanced the smaller gear one place, thus "carrying" to the hundreds place. Gift of Gwen and Gordon Bell.

The oldest mechanical pocket calculator, designed by Englishman Samuel Morland (1625-1695) in 1666, avoided some of the mechanical problems that plagued the Pascaline. Morland did not link together the gears for different digits. Instead, each time a digit gear completed a full turn it advanced the small gear above it one place. At the end of a problem the small gearsindicated how much to add (carry) to the next digit places. From the collection of the IBM Corporation.

The Addiator was a very inexpensive and widely-sold pocket calculator. Introduced in 1920, over 100,000 were sold the first year. The Addiator was not truly mechanical in operation. The user added by sliding either up or down strips of metal with numbers marked on them. No gears or inter-linked parts were involved. The basic idea was first invented in 1889 by a Frenchman named Troncet. Troncet called his calculator the Arithmographe. From the collection of Gwen and Gordon Bell.

Slide Rules. Edmund Gunter (1581-1626) was the first to construct a scale rule that could be used to multiply. He divided his scale according to Napier's principle of logarithms, so that multiplication could be done by measuring and adding lengths on the scale. In about 1630 William Oughtred (c.1574-1660) improved upon Gunter's idea by fixing two rules together so they could slide against one another.

Slide rules were not the only widely used analog calculators. Quadrants evolved from instruments used for measuring angles between stars in ancient Babylonia. In the 16th century scales were etched on these devices which made them more useful to laymen as calculators. Gunter was one of those most responsible for the quadrant's improvement and use. Other popular analog calculators were the proportional compass and the sector.

In the seventeenth century, the English government devised an efficient system for taxing ale and wine by producing a slide rule to help the assessors calculate the tax, right at the barrels. The alcohol tax was levied only on the amount that had been sold, and the slide rule allowed the assessor simply to determine the liquor that remained in the barrel. He used a gauging rod, like a dip stick in a car.

The first such slide rule was described in 1683 by Thomas Everard. In 1739 Charles Leadbetter improved upon the design by adding scales that could calculate the contents of a keg whether it was standing on end or lying on its side. The rule was used with a folding gauging rod to measure the depth of liquor in a keg. Sometimes tax assesors had their rule and gauging rode fit into a cane; not quite a pocket calculator but certainly of the same notion.

Slide rules were the work horse of scientific calculation for many decades, They were fast and reliable, and an experienced user could perform a long and complex calculation with ease.

The "Unique Log-Log" slide rule, and the later Dietzgen Redirule are slide rules designed for the shirt pocket. In general, the shorter the slide rule, the less accurate it is. From the collection of Gwen and Gordon Bell. Gift of I. Bernard Cohen.

Circular slide rules operated on the same principle as straight slide rules, but they took up less space. Both William Oughtred and his student Richard Delamain claimm to have first thought of the circular slide rule.
(1) A general circular slide rule. Gift of Stanton Vanderbilt.
(2) This slide rule was used by pilots to estimate arrival times, and to calculate other aspects of their flight according to changing conditions. From the collection of Steve Kallis.
(3) A bombardier would have used this slide rule to calculate the chances of destroying his target under various conditions. Gift of David Martz.
(4) Harvard Project Physics circular slide rule could be slipped into a student's textbook. Gift of I. Bernard Cohen.
(5) This homemade version made by Charles Bachman helped the family compare the price of goods at the grocery before the

days of unit pricing. Gift of Charles Bachman.	

Slide rules had two drawbacks. First, slide rules were only as accurate as the fineness of their scales, because they were analog calculators and measured quantities. If the scale were any finer you could not read it. Notice how you have to estimate the position of a three-digit number on the scale. This degree of accuracy, however, was generally enough to estimate the answer to most scientific and engineering problems. Second, slide rules have no decimal points. The same mark can be read as 0.125, 1.25, 12.5, or 125. The user had either to keep track of the decimal point or to place it wherever it was reasonable when the problem was finished.

Until the 1970s, when an engineer wanted a quick answer to a problem, he usually reached for his slide rule. The slide rule was designed to simplify complicated calculations. Leather cases that could be clipped to the belt were often used by scientists to carry large slide rules with them wherever they went. The slide rule (or "slip stick" as it was nick-named) was the constant companion of engineers and scientists. Slung from the belt or stuck in the pocket, it was the mark of the serious scientist.

Mechanical Multiplying Calculators. In 1671, Leibniz conceived the idea of a multiplying machine by repeated addition, and constructed his earliest model in 1694. Since 1879 it has been preserved in the Royal Library at Hanover, where at one time Leibniz was the librarian. An important feature of the machine was the stepped wheel which is the basis for many subsequent mechanical calculators. Most of these are quite large and heavy, couldn't even think about being portable - not to mention fit into the pocket.

The Curta was the only multiplying, mechanical pocket calculator. Built with the precision of a fine watch, it took mechanical calculation to its finest development. However, like a fine watch, this degree of mechanical precision was not cheap. The Curta sold for close to $150 in the early 1960s. Like many of the fine pocket instruments of earlier days it became a symbol for the need for precise calculations and was closely associated with car rallying. Its manufacturing costs only increased and by the mid- 1970s electronic calculators were faster, smaller, lighter, more powerful and less expensive than the Curta.

The Curta was invented by Curt Herzstark and manufactured in Liechtenstein starting about 1950. Each part was manufactured to a tolerance of .001 millimeter. Gift of Robert Brickford.	

Electronic Calculators. By the mid-1970s electronic calculators reached the masses. The development of very small and cheap electronic circuits for computers during the late 1960s and early 1970s allowed small electronic calculators to be constructed and sold inexpensively. Over time, calculators became even more sophisticated, cheaper, and smaller.

Today electronic calculators can:

- store numbers and information like early pebble calculating systems and wax tablet records,
- add large numbers quickly like the abacus or Webb Adder,
- multiply rapidly like Napier's Bones, and the Curta,
- quickly find the values of mathematical functions like mathematical tables or slide rules,
- be programmed to perform complicated and lengthy calculations at the push of a button,
- perform whole new tasks such as translating languages and dialing phones.

The Hewlett-Packard HP-35 was the first scientific pocket calculator. It could very quickly and accurately perform many of the slide rule functions that were too complicated for simple fourfunction calculators. It was nicknamed the "electronic slide rule." Thanks to the speed of electronic circuits, the HP-35 could calculate the logarithm of a number at the push of a button. When introduced on February 1, 1972, the HP-35 cost $395.

Prior to the first scientific calculator, the HP-35, finding the value of a function (such as the sine of an angle) meant looking it up in a table, or being satisfied with the limited accuracy of a slide rule. The HP-35 could instantly calculate the sine of an angle to ten decimal places. The same is true of other trigonometric functions and logarithms. Gift of the HewlettPackard Company

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Highlights from

The Computer Museum Report

Volume 19 ---- Spring 1987

Contents of Highlights

Memories
Stories Behind the Devices

Gwen Bell

The computer memories on the cover are evocative of the collection of memory devices held by the Museum and of many people's experiences in computing. A large number of these devices were used to store the program, and thus they represent the software as well as the hardware dimension of computing.

The collection of items was made by Dr. Oliver Strimpel and me and was then refined by David Sharpe, the photographer. Our goal was to provide a beautiful and evocative image. In this article I will use the image to tell more stories of the Museum's holdings. In describing the stored program computer, John Von Neumann used the term memory instead of storage because he likened the computer to the human nervous system. Despite a variety of efforts to call computer memory, storage, memory is the word that has stayed with us. Storage is often used for secondary files, such as magnetic tape or discs, and tertiary (archival) memories, such as tape storage that requires human intervention before it is accessed by the computer.

The collection and the poster also include devices for remembering that predate the computer. The PMS classification system described in Bell and Newell's, Computer Structures, was used to develop the collection. Their appendix described and further classified memories into three main classes: either machine read or written, machine readable only, and readable and writeable memories. Three other features are considered important: access, portability, and permanency. Of these, the most important is the form of access, i.e., whether it is linear, cyclical, or random. The table shows that the illustrations on the poster are indeed representative of the various sections of the memory taxonomy.

Pre-computer Memories: Read or Write

Linear Access

One of the early books, Charles Hutton's, Table of the Products and Numbers, 1781, contains the products of the numbers 1 through 1000 by the numbers 1 through 100, and squares and cubes of numbers. This illustration shows all the figures on a line off by 1000. Page from Hutton's - with correction.

Table Look-up. Napier's Bones, devised at the beginning of the 17th century, were a form of memory for the multiplication tables. Then after John Napier devised logarithms and with the development of calculus, the answers to a series of simple equations were printed and sold widely as books. This phenomena of the book of tables continued through the 1960s. The problem with many of these books was their accuracy. The calculations were done by hand, then the type was set by hand. Sometimes final corrections were made by hand after proofreading..

The Difference Engine was designed by Charles Babbage to accurately produce and print pages of tables of differences. This was later built by Scheutz and produced books of differences. Howard Aiken, whose idea was to produce Babbage's Analytical Engine, desired to produce tables of Bessell Functions of astronomical observations. After the Harvard Mark I had completed these computations, the future use of the computers was questioned

"Complete Mathematical Chart" by Goodchilde, c. 1900 (item 12 in the poster), is two cardboard pages that were available for easy reference. The Museum's collection has a variety of examples of several cardboard pages filled with numbers and very thick books of the thinnest possible paper allowing for as much information as possible. Specialized pocket calculators and computers still maintain frequently used information in lookup tables. General purpose machines perform most calculations rather than relying on lookup tables.

Punched Cards. In the 1790s, Joseph Jacquard designed a machine to weave silk patterns based on the ideas of Bouchon, deVaucauson and Falcon. This machine used an automatic harness controlled by punched cards connected in a roll that held the pattern. Babbage was inspired by the Jacquard loom and planned to use card input in the Analytic Engine.

Hollerith's punched-card system for the 1890 U.S. Census was the first to use cards for data processing. The size of the Hollerith card was based on the size of the dollar bill at the time, and the round punches were those used by trolley conductors. Hollerith's Computing, Tabulating and Recording Company hired Thomas J. Watson, Sr., as its President, and in 1924 the name was changed to International Business Machines. While the eighty column "IBM" card with rectangular holes became the standard, other sizes and shapes of holes were used for special purposes and niche markets.

The Computer Museum's collection includes a very special punched card system developed by Powers-Samas for the Institute for Terrestial Ecology in the UK. (Item 4). Field data on the location and species of flora and fauna were written directly on the card to be punched. In the late forties, Professor Maurice Wilkes, who was building the first stored- program computer, consulted on the design and development of a special printer that would take the data from the cards and produce dot maps of distributions in the British Isles.

The 19th century silk looms, where cards were used to create intricate patterns inspired Babbage to use cards to hold other kinds of information.

Computer Memories: Read or Write Linear Access

Punched Cards. Most of the first computers adapted card systems for the input and output of data. The UNIVAC, the first commercial computer, had a 90 column card with round holes (Item 9). Setting one's own standard is often done to get or keep one part of the market. At the outset, when all the competitors are scrambling, the "winner," or de facto standard, is not always obvious. Then, those without standard products often make special compensations to win new customers. The 80 column IBM card became the standard, and UNIVAC came out with the Solid State 80/90. "Solid State" referred to the fact that it had 700 transistors and 3,000 ferractors or magnetic amplifiers and only 20 vacuum tubes. " 80/90" meant that it could deal with either the IBM 80 or UNIVAC 90 column cards.

One of the many problems with card storage was their very bulk and lack of density of information. For example, 60,000 cards were required to store the master program for the AN/FS Q7, SAGE system computer built in the late 1950s. They took up 24 cubic feet of space and had to be kept in order. (Later, a reader was developed that could accept cards in any direction or order.) To extend the life of card computing IBM developed System 3 with a smaller card that more than doubled the density of information. This provided no competition, however, for the floppy disk or integrated circuit.

IBM 80 column card with rectangular holes

Punched Paper Tape. While the ENIAC used cards for input/output, the EDSAC, the first stored program computer built by Professor Maurice Wilkes at Cambridge University, used punched paper tape (Item 10). This form of input and storage of programs and data, adapted from telegraphy, was quite common on the early university computers. Flexowriters were used to punch tape that could be spliced together with previously punched subroutines. Flexowriters were replaced by Teletype, later Model 33s. Paper tape continued as a form of input up through the beginning of the micro-computer era. For example, Bill Gates delivered the first BASIC interpreter for the 1975 Altair on punched paper tape.

Flexowriters were used to punch the papertape for the input of data for many of the first computers. These machines and their antecedents were cheaper, stored upper and lower case, and had a better human interface than the punched-card machines. They led directly into the development of computers with keyboard input.

Computer Memories: Read or Write
Random Access Patchboards. The pegboard program tray from the Ferranti Argus 200 (item 11) contained the master program for the machine. Master programs, the precursor of operating systems, were not placed in a read-only memory because the programmers wanted to be able to change them. This meant taking out the tray and replacing the magnetic pegs to make a different set of connections. The early users had even greater difficulty keeping up with the new versions of fundamental operating systems since programmers could come in and change things overnight.

Computer Memories: Machine Readable
Random Access

Rope Memory. The design of the early space computers in the late fifties and early sixties preceded the availability of reliable integrated circuits. In 1962, the designers of the Apollo Guidance Computer took a bold step in choosing integrated circuits (invented in 1959) for the logic component of the machine, but they went with more conservative choices for the memory. The computer had 1024 16-bit words of core memory and 24,576 16-bit words of read only fixed memory made of wired-in ropes and cores. R. L. Alonso and J. H. Laning, two of the AGC designers, described these as "compact and reliable devices." The truly important decision was that the astronauts would be able to use a computer that had a 2K erasable memory that they could control.

For a short while, a small Massachusetts company tried to make a market that specialized in weaving rope memories for computers. This technology was used for the character set for Digital Equipment Corporation's 338 display unit available in the mid-sixties.

Computer Memories: Readable and Writeable
Cyclical Access

Cyclical memories are still used today primarily as secondary storage in the form of disks and tapes. Prior to the invention of core memory, early computer designers had two choices of primary cyclic memories. Delay lines were reliable but slow and required special talents in logic and programming. The less reliable CRTs were adapted for use as memories by Frederick Williams of Manchester University and called "Williams Tubes."

Delay Lines. Maurice Wilkes, in building the EDSAC, and Alan Turing, in the specifications of the Pilot ACE, chose delay lines. As a result, delay lines were used in English computers throughout the fifties.

The short magneto-restrictive delay line is from Ferranti Pegasus (Item 8). In describing the design philosophy of the Pegasus, its designers W. S. Elliott, C. E. Owen, C. H. Devonald, and B. G. Maudsley, discuss the machine's "rhythm." This rhythm is based on the access to the primary memory of 55 single 42-digit word magneto-restrictive delay lines. A basic 3-beat rhythm was established. Beat 1 of oneword time extracts two orders from the memory; beat 2 of two-word times obeys the first order; beat 3 of two-word times obeys the second order. (Clearly a waltz with a first quickstep.) Programmers of delay-line machines learned to optimize the rhythm and were heard to regret the simplicity of programming for all the later machines based on random-access primary memories.

Drums and Disks. Magnetic drums were the earliest form of secondary magnetic storage. Prototype magnetic drum computers included the Harvard Mark III and the ERA 110 1. The magnetic drum provided a large amount of slow memory at relatively low cost. Typical drum-storage systems are 8-20 inches in diameter and revolve at 1, 500-4,000 rpm. There were literally dozens of magnetic drum computers of varying capacity that were the small to mediumsized computers of the first generation.

In the late fifties, the IBM 305 RAMAC (random access method of accounting and control) was among the first -- if not the first -- data processing system to employ a magnetic disk file permitting direct random accessing of records. The system, with 50 disks, stored 20 million characters.

When disks were introduced as a secondary storage device in the late fifties, they had the characteristic of looking like the platter set on a contemporary jukebox. The IBM RAMAC for example had a total of 50 disks.

The LGP-30 was one of the many small scale drum computers sold in the fifties. Built in 1956, in 1962 it rented for $1300 a month. The drum on the far right held 4K bits [actually 8 K 30 bit words] of information.

Computer Memories: Machine Readable
Linear Access

Magnetic tape. Magnetic tape has had the advantage of being a relatively stable product, with specifications for its physical or magnetic properties changing very little. Archival tapes from two decades ago are generally still readable. In contrast, disk technology has rapidly changed.

The "DEC-tape" (Item 13) is a non-standard tape that can be thought of as an important component of mini-computers and a precursor to the floppy disk. The small tape units were designed by Wesley Clark for the LINC computer. Two dozen LINCs (Laboratory Instrument Computers) were built by their users at MIT in 1962. The LINC-tape was small, removable and portable. User's could carry their own around, the same way that users today treat their system and data disks. DEC reverse- engineered the tape and used it on its own LINC-8 system and then on the PDP-12.

Computer Memories: Machine Readable
Random Access

Williams Tubes (Item 7). Professor F. C. Williams of Manchester University developed the first random access computer memory. Julian Bigelow, who was building a computer at Princeton's Institute for Advanced Studies with von Neumann, recalls Williams and his lab: "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 out of surplus World War II radar parts strictly on his own inspiration in the middle of which were two cathode-ray tubes storing digits 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 . ...The whole technique depends upon clever exploitation of the fortuitous secondary electron emission properties of cathode-ray-tube phosphor screens - phosphors that are chosen and incorporated purely to give good visual response without regard for secondary electron emission. In this sense it was a lucky accident that the scheme worked at all." (Julian Bigelow, "Computer Development at the Institute for Advanced Study," in A History of Computing in the Twentieth Century, N. Metropolis et.al., 1980.)

Despite all of this seeming "black magic" around the Williams tube, it was successfully used by IBM on their 701 series of computers.

The Williams tube was used as a graphic device. Each instruction was read in twice on the same line. If it agreed then a check mark appeared on the second halt of the line. Below is a detail of the screen.

Short Chronology of Major Events in the Development of Core Memory Abstracted from Emerson W. Pugh, Memories that Shaped an Industry, MIT Press, 1984.

1946. 1 /46 Jay Forrester proposes a computer at MIT
1947.
1948.
1949. 6/49 Forrester begins documentation in his notebook of a memory using magnetic materials
9/49 An Wang describes a shift register using magnetic toroids of Deltamax
1950. 8/50 M.K. Haynes thesis describes his coincident-current magnetic core memory proposal.
9/50 Jan Rajchman of RCA files a patent application for a coincident-current magnetic memory.
10/50 Forrester initiates ferrite material work at MIT
1951. 5/51 Forrester files for a patent on his magnetic core memory
12/51 Successful operation of a 16x16 array of metallic cores at MIT
1952. 1 /52 2x2x2 ferrite core memory built in Hayne's group at IBM
5/52 4x4x4ferritecore memory operates at IBM
1953. 5/53 First ferrite core main memory operates on MIT Memory Test Computer with a 32x32x17 array
1954.
1955.
1956. 1 /56 IBM ships 702, 704, and 705 computers with ferrite core memories.

Core Memory. Both the IAS machine and MIT's Whirlwind made do with a version of the Williams tube as their original memory devices. But in both cases, the concept of using some sort of magnetic random access device was under consideration.

The IAS group was working with Jan Rajchman of RCA to develop a fast parallel memory to operate the arithmetic unit. After two years of development no wholly operative memory had been produced. Julian Bigelow remembers, "von Neumann and I made an attempt to list all the variables which would have to be kept under control to produce a 50% yield of successful Selectron tubes covering a range of digital capacities from the original goal of 4096 digits per tube, down through 2048, 1024, 512 etc. In any event, although the Selectron tube held out intellectural respect cared admiration, we had increasing doubts that it would provide something we could use in the near future." Several years after the IAS Computer was running, a 256 digit Selectron tube was delivered to the Rand Group for the Johnniac (Item 19).

About seven years passed between the beginning of the invention of core memories for computers and their delivery to customers within a commercial product. Over the next twenty years, until the late seventies, core memories were the predominant form of primary memory. After 1971, when IBM shipped their first system with allsemiconductor main memory, engineers tried to pack greater and greater density to compete with these new products. The 1972 planar core memory board from DEC (item 3) achieved two bits of information from each core by reading the memory at two different voltages. Core is still used in a few systems to gain the reliability that comes from a stable memory regardless of power failure.

The original diagram shows only the coordinate wires for the core. The diagonal wires on the manufactured core plane provide the read element for each core.

Entrepreneurism:
The Past, Present and Future of Computing in the USA

William Norris, Chairman Emeritus Control Data Corporation

The genesis of Electronics Research Associates (ERA), one of the first computer companies, was the U.S. Navy's World War II Communications Supplementary Activity in Washington (CSAW). Often referred to as "Seesaw" because of its initials, its primary mission was to intercept and decode enemy messages. The mission was of such critical importance that no expense was spared to assemble the best talent and develop the technology needed to assure maximum success.

Toward the end of the War, Dr. Howard Engstrom and I, both members of CSAW, put a plan together to preserve the unity and continuity of the efforts and the team. We suggested that a significant number of the team would form a private company that would make their services available to the Navy under contract. The new company would, at the same time, develop other business based primarily on electronic digital circuit technology. Late in 1944, the Navy accepted our proposal and all we needed was financing.

William C. Norris seated at the console of a 3600 Computer in 1964.

Venture capital hadn't yet been invented and information about the nature of our expertise was highly classified. About all that we could say was that we had a group of talented professionals with unique expertise in the design of electronic digital circuits that had potential for new products in a number of important fields.

Seventeen companies and a number of individuals in the Washington/New York area were contacted. We visited J. Prespert Eckert and suggested that we undertake a joint activity. Eckert said that the plans for his company had pretty well jelled and that he didn't want to consider that possibility. Later, fate destined us to get together when Eckert-Mauchly became a division of Remington Rand in 1950, as did ERA in 1952.

Admiral Lewis Strauss, Assistant to Navy Secretary Forrestal, was one of the partners of the Wall Street firm of Kuhn, Loeb who were identified as a source of financing. Since security was not a constraint in talking to Admiral Strauss, he was greatly intrigued by the concept and said that he would finance the company personally even if his partners in Kuhn, Loeb were not interested. Before signing, Admiral Strauss asked that a member of his staff, Commander Paget, review the proposal. Admiral Strauss pointed out that Commander Paget was planning to establish a consulting company that he was personally financing. Paget concluded that while our plan was interesting, it wasn't economically viable. Both Strauss and Kuhn, Loeb backed out.

The final chapter of this incident was written 25 years later when Control Data acquired the Commerical Credit Company, and the firm of Cresap, McCormick and Paget was one of the consultants proposing to help. When their proposal was presented, the introduction contained a message from Mr. Paget expressing the hope that with the passage of time I had forgiven him for his erroneous conclusion. Indeed, 30 years and the success of Control Data, especially the latter, had mellowed my resentment.

Yet in 1945, Admiral Strauss's rejection was a devastating blow because we were led to believe that we had located our sorely needed financing after a long and arduous hunt. Even worse, by then the war had ended and time was running out.

Then, late in 1945, we learned that Northwestern Aeronautical, a company located in St. Paul, Minnesota, that was a war-time contractor for troop-carrying gliders, was looking for a new direction. After several meetings with the President, John Parker, a deal was struck, and ERA had a home in St. Paul.

Incorporated in January 1946, ERA's equity ownership was divided equally between the founder group and the financial group headed by Mr. Parker. 100,000 shares of stock were sold to each group to provide $20,000 total equity. In addition, Parker's group guaranteed a line of bank credit of $200,000.

Superb human capital and effective government contracting methods helped us to meet the requirements of CSAW. The R&D work for this agency was performed under cost plus fixed fee contracts. This was advantageous and effective because it allowed wide flexibility in setting initial specifications and altering them to gain maximum performance. Such contracts came both from the Bureau of Ships and the Office of Naval Research. This type of contract was a new and enlightened approach by the Navy. In combination with entrepreneurial enterprise, not only were the needs of the Navy met, but many important advances were made in computer technology. In the process of performing a large number of R&D contracts, ERA built up a vast reservoir of technology, evidenced by the large number of spin-off companies that were spawned.

ERA built the first commercially available digital computers, the 1101 and 1103, and also developed and manufactured magnetic storage devices. By 1952, ERA's growth was outstripping its limited capital base, and the only alternative for maintaining growth was to merge with a large company. I stayed on as general manager of the ERA Division of Remington Rand. When Remington Rand merged with Sperry to form Sperry Rand, I became general manager of the Univac Division, where all computer activities were consolidated.

Although Sperry Rand had acquired the industry's two leading entrepreneurial computer companies with a major part of the leading edge technology in the industry, namely Eckert- Mauchly and ERA, they were unable to capitalize on the technology lead. I resigned to form Control Data.

Contol Data's first day on the New York Stock Exchange, March 6, 1963.

The shipment of the First 1604 computer to the U.S. Navy.

Control Data Corporation

In July 1957, CDC was incorporated based on an initial financing by the sale of 615,000 shares of stock to the public for $1.00 per share. Control Data was the first publicly financed new computer company. Part of the ERA team came with me and we focused on a line of engineering and scientific computers that included supercomputers at the top.

My definition of a supercomputer is "today's most powerful, general purpose, computer." That definition implies that there can be only one supercomputer at any one time. Since any computer's power varies for different applications, this means that there may be two or three machines that deserve to be called supercomputers at any one time. Thus, in their day, the ENIAC, EDVAC, ERA 1103, CDC 6600, CDC 7600, CRAY 1, and CDC Cyber 205 could all be legitimately called supercomputers. In the early seventies, CDC also initiated the Plato computerbased education system in cooperation with the University of Illinois and the National Science Foundation, because computer-based education is the most significant application area. High quality relevant courseware consisting of more than 15,000 hours on material in a broad range of 150 subject areas is currently available.

Education and Competitiveness

Computer based education not only delivers and manages instruction, it also provides the capability for reducing or eliminating the time consuming administrative tasks associated with teaching, thereby making more efficient use of instructional resources. This allows teachers to spend more time with students and gives students more time for improving their skills. Unfortunately, utilization of computer- based education has not kept pace with the growing availability of high quality courseware and decreasing costs of hardware and software. The adverse consequences of this lag are especially serious in the K-12 educational spectrum where the basic underpinnings of a skilled work force are formed.

The decline in the ability of our work force to handle comprehensive notions of science and technology translates into an important factor in declining U.S. competitiveness in world markets. Ample evidence is available to show that the Japanese school system far exceeds ours in its ability to prepare educated workers for business and industry. For example, youngsters in Japan spend more time developing their ability to handle science, math and foreign language than in the USA.

Knowledge is becoming an increasingly important factor in the workforce, Unless education and training is significantly improved, our technically illiterate work force will place us at an even greater competitive disadvantage. Considering all the constraints, the only practical solution is a massive increase in the use of computer- based education.

Environment for Entrepreneurship

Despite the critically important role entrepreneurism has played in the computer industry and indeed in our entire national economy, the environment for small enterprise innovation is deteriorating along with our competitive position in world markets. Most markets suffer from unprecedented domination by multinational corporations, many of them foreign-based, to the disadvantage of medium and small companies with limited resources, especially for manufacturing.

The passage of the Mansfield amendment to the military procurement authorization act of 1970 required that research be related to weapon systems. This act significantly reduced access to technology by small companies and gave large military systems contractors more control over research.

Small companies receive less than three precent of total government R&D funds. Given the record of small enterprise as a major source of innovation, this resource is far from being utilized. The small business innovation research program passed by Congress about 1982 has only helped modestly.

Fortunately, venture capital, a major stimulus to small enterprise innovation, continues to be in plentiful supply. Unfortunately, the innovations are made in the pre- venture capital stage, where government R&D can greatly help. Seed capital is required to advance technology from the research and idea stage to the point where venture capital commitments can be made.

Broadly speaking, our foreign competitors, especially Japan, have greatly accelerated research and development, dramatically increased the number of trained scientific and technical personnel, reduced needless and wasteful duplication of technology development, fostered growth and lowered the cost of capital in carefully targeted industries. The Japanese government has promoted cooperation among industry members at the base technology level as a key ingredient for success.

The declining US competitiveness is largely related to inefficient and, at times, inept management of technology. Public/private cooperation is needed to substantially increase the efficiency of research, development and manufacturing. Three new institutions provide models: The Microelectronics and Computer Technology Corporation; A Job Creation Network; and The Midwest Technology Development Institute.

The Microelectronics and Computer Technology Corporation (MCC)

The MCC was established in 1982 in Austin, Texas. It has grown from eleven to twenty-one participating companies from the US computer and semiconductor industries. Base technologies are developed by MCC's scientific and engineering talent and provided to the members. Member corporations can each add their own value and continue to compete with products relating to their own freely selected markets. MCC also licenses technologies on reasonable terms to others, including small companies.

A ten-to-one leverage is gained by the member companies in MCC. If every industry had a similar cooperative arrangement, it would provide a much-needed boost to innovation and competitiveness.

The Microelectronics and Computer Technology Corporation (MCC) Corporate Membership List.

Advanced Micro Devices, Inc. Sunnyvale, CA Bell Communications Research, Inc. Livingston, NJ Digital Equipment Corp. Maynard, MA Harris Corp. Melbourne, FL Honeywell Inc Minneapolis, MN NCR Corp. Dayton, OH Westinghouse Electric Corp. Pittsburgh, PA Allied-Signal Inc. * Morristown, NJ Boeing Co. Seattle, WA Control Data Corp. Minneapolis, MI Eastman Kodak Co. Rochester, NY General Electric Co. Fairfield, Conn Lockheed Corp (Lockheed Space and Missile Co.)* Sunnyvale, CA Martin Marietta Corp. Bethesda, MD 3M CO. St. Paul, MN Motorola Inc. Schaumburg, Ill National Semiconductor Corp. Santa Clare, CA Rockwell International Corp. Pittsburgh PA Unisys Corp.* Detroit, MI Hewlet-Packard Co. Palo Alto, CA
* Companies that have announced they are leaving MCC at the end of 1987.

Job Creation Network

The Job Creation Network operates at the community level to improve initiatives for expanding innovation. It consists of three elements.

1. A cooperation office is a nonprofit organization that helps a new company shape a business plan, obtain financing, or locate a base technology. The staff is bolstered by a volunteer advisory panel of experts.

2. A seed capital fund is accumulated from a consortium of state and local government and private investors with tax credits made available.

3. A business and technology center provides consulting services, shared laboratory, manufacturing, office or other services to facilitate the startup.

Aggressive programs have been established in Illinois, South Carolina, Minnesota and Canada

The Midwest Technology Development Institute (MTDI)

The MTDI was established in 1985 with nine member states. MTDI has the threefold objective of:

1. expanding technological cooperation among midwest universities and industry to increase the efficiency of research and the commercialization of the results;
2. extending technological cooperation to include universities in foreign countries;
3. providing a mechanism to increase the availability of technology to industry, especially small businesses and to achieve an equitable transfer of technology between the US and foreign countries.

Unbalanced Technology Flow

A partial list of reasons for the inequitable technology flow that goes from the US to Japan includes:

- A significant part of Japan's basic research is carried out in government laboratories that are closed to foreigners.
- US companies cannot participate in Japanese government-funded R&D projects that have explicit commercial objectives, nor, for the most part, do US companies have access to Japanese patents.
- Small US companies are a major source of technology for Japan that is obtained by licensing or acquisition. US enterprise does not have a similar opportunity.
- Japan has virtually unlimited access to US research.
- The best Japanese graduate students come to the US and are supported both intellectually and financially and do not repay this capital investment.
- The US has not diligently pursued the acquisition of Japanese technology.

One of the first corrective actions was taken in 1986 with the amendment of the Stevenson-Wydler Innovation Act that gave the directors of the US federal laboratories discretionary authority to deny access to research to any foreign country that does not grant similar privileges to American organizations.

Implementing equitable technology flow agreements with other countries will require that the US keep track of technology transfer. MTDI is playing a major role in establishing a measurement system,that will include mechanisms for inventorying and tracking technology. They will also institute a large scale program aimed at helping transfer Japanese technologies to small US companies.

Technology Momentum

The flourishing of entrepreneurial enterprise during the decade between 1945 and 1955 provided the momentum that accelerated through the early 70s to put the US into world leadership in the computer industry. A great deal of credit must be given to the Navy, especially the Office of Naval Reserach Program in Computing for the stimulation and support of the development of computer technology until it was ready for commercialization. This early support coupled with entrepreneurism was a major factor in helping to build the momentum that propelled the United States into world dominance of the computer industry. Indeed, leadership in computer technology was also a catalyst to innovation in other fields and until recently, the US has been dominant in technological innovation in the world.

The position has been deteriorating in the last decade. Unless corrective action is undertaken with massive technological cooperation and with an environment for entrepreneurial enterprise, the erosion will continue. If the corrections are made then entrepreneurial enterprise will again realize its potential and play a leading role in expanding innovation on the scale necessary for assuring the wellbeing of the country.

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Highlights from

The Computer Museum Report

Volume 20 ---- Summer/Fall 1987

Contents of Highlights

Smart Machines

Oliver Strimpel

The unifying theme of the Smart Machines gallery is to demonstrate how machines do things that have hitherto been the province of intelligent human activity. We were determined to convey to our visitors the tremendous sophistication of the human mind and body, as well as some of the difficulties scientists face in their attempts to replicate even the simplest of human activities. The combination of A. I. and robotics was straightforward enough: we wanted to demonstrate both the mental capabilities and the physical dexterity of today's machines. This article attempts to explain how the various live exhibits selected for Smart Machines exemplify past and present trends in A. I. and robotics.

The exhibit is grouped into six sections: language understanding, knowledge- based systems, game-playing, robot sensing, mobile robots and robot arms. The historical time-line and robot theater are described in the next article.

Language Understanding

One of the major conclusions of A.I. research during the 1970s was that knowledge and language could not be clearly separated. The early attempts to understand or translate language on a word-by-word basis failed. However, research has continued along several lines, and progress has resulted in commercially successful products.

A grammar correction system from Houghton-Mifflin shows how much a computer can do without any knowledge of the meanings of words. Visitors can watch the grammar checker find mistakes and correct them automatically.

Unlike a grammar checker, parsing is just the first stage of a program that actually tries to understand the meaning of a sentence. In a natural language interface program, the knowledge resides in the database. However, the questions stated in English must be translated into a machine language query to the database. Our exhibit features Datatalker, a natural language interface from Natural Language, Inc. It asks visitors to type in information about themselves, which it stores. It then invites questions in plain English about previous visitors. The program's task is eased because it expects a question about something in its database. After parsing a visitor's question stated in English, the program tries to extract the sentence's meaning, and, if appropriate, converts it into instructions to search through its database for information that will answer the question. The result of the search is translated back into an English reply. Other parts of the program keep track of the dialog, deciding when responses are adequate.

To go beyond a simple question and answer conversation, computers need a much wider and deeper knowledge. The exhibit addresses this enormous problem by demonstrating some of complexities of building a real computer like HAL in the film 2001: A Space Odyssey.

Two exhibits are conversational programs that pretend to know more than they do. ELIZA, the classic computer psychotherapist program written by Joseph Weizenbaum in 1966, takes key words from the visitor's typed-in text and uses them to trigger stock questions. It also repeats the user's words, turning statements into questions. ELIZA exploits its role as a non-directive therapist to justify its extreme passivity. In contrast, RACTER converses volubly with the visitor on many arcane topics. Like ELIZA, it has no model of the world, but responds to key words in the input text by concocting sentences based on standard forms. It attempts to skirt around its lack of understanding by making a virtue out of being zany. These programs are not presented as A.I., but as illustrations of the limitations of approaches that use words without knowledge.

Knowledge-Based Systems

The greatest number of useful applications in the field of A.I. have emerged from rule-based expert systems. Several hundred expert systems perform tasks ranging from diagnosing failures on gas turbines to suggesting which pesticides to use on a particular crop. In general, a Museum should exhibit genuine examples of its subject matter.

However, expert systems are tools aimed at the technical user and would be totally incomprehensible to the majority of our visitors. As a compromise, we included one "real" expert system, somewhat modified for the Museum by its author, Randy Miller. The system is Quick Medical Reference (QMR), a medical diagnosis system that contains descriptions of nearly 600 diseases. Visitors can browse through the system, using it like an electronic textbook indexed either by disease or by symptom. Alternatively, visitors can retreive a patient's case, make QMR diagnose it, and compare QMR's hypothesis with one of their own.

We assembled several highly instructive and entertaining "nonreal" rule-based systems to demonstrate the capabilities and internal workings of expert systems. In the Haymarket exhibit, visitors haggle with up to three different rule-based storekeepers to buy a large box of strawberries. The simplest, Noah Budge, has only 8 rules and never budges on his price. Eventually, he will kick you out of the store if you don't give him what he's asking for. Visitors can choose Ho Nin with 30 rules and

Nora Logical, the sophisticated storekeeper with over 100 rules. Another rule-based demonstration is a wine-advisor. This proceeds via a two-way spoken conversation. Visitors are asked questions about the type of food planned for the meal and what their tastes are in general. They respond by speaking into a microphone. After up to 10 questions, the computer makes a specific recommendation.

Several rule-based systems dealing with the arts are also on display, including a musical score follower (right) and a drawing expert (below). The goal is to demonstrate the application of rule-based programming techniques in non- technical domains. A computer composition system by Charles Ames generates rock and jazz pieces, which it performs through a Kurzweil 250 synthe- sizer. After selecting a musical style and a model, such as the twelve bar blues, the program selects instruments and then com- poses the rhythm, assigning each note a duration that depends in part on whether it is a basic, ornamental or cadence note. Finally, pitches are selected according to a set of about 20 rules. The rules make the notes conform to the harmony, create a melody and avoid repetition. The music is surprisingly convincing.

In contrast to all the systems described above, which represent knowledge as sets of rules, TALE-SPIN is based on scripts. This program came from the work of Roger Schank's group at Yale on language understanding. TALE-SPIN is a program that generates stories with a simple "point" somewhat reminiscent of the simpler Aesop's fables. The program simulates a world of char- acters who do things because they have problems to solve. These consist of fulfilling simple goals, such as satisfying hunger or thirst. Visitors select a main character -- Joe Bear, Irving Bird or Lucy Lamb -- and also determine the goals and character traits of the players. The program has a model of its characters and ensures that their behavior is rational. For example, if Joe Bear is thirsty and sees a river, he will try to get to the river.

In addition to rules, knowledge can be represented as frames, semantic nets and scripts. These are illustrated by panels in the exhibit.

Game-Playing

In addition to being fun, computer games are a valuable testing ground of ways to search through enormous numbers of alternative solutions to a given problem. Typically, when people play a game, they rely on knowledge of the opponent's ability and on an understanding of what it takes to win. Machines, on the other hand, rely on searching many possible moves to determine the best outcome. Research efforts have concen- trated on optimizing the search for moves in chess. One approach is to perform the search in the proper order so that unpromising avenues can be elimi- nated early on. Another approach seeks to give the com- puter knowledge about chess, increasing its ability to "size-up" a given position. Hans Berliner and his colleagues at Carnegie-Mellon University used both approaches to build the world's strongest computer chess player. Their program, called Hitech, has custom hardware to generate and evaluate up to 200,000 moves a second. This enables it to search about 11 half-moves ahead while playing in a tournament. In addition, Hitech's board knowledge is equivalent to a search of a further three half-moves.

Visitors can also play tic-tac-toe and five-in-a-row and choose the computer's strategy to be one of look-ahead search, voting or random. The program offers graphics that give an "X-ray" view of the program's deliberations.

A checker player by David Slate can beat all but the most serious players. Finally, in the game "How the West Was Won," the computer plays two roles: opponent and tutor. This is a numbers game, designed to help children gain familiarity with arithmetic. The computer tutor analyzes one's moves and suggests possible improvements. It never scolds or repeats itself and lets the player discover the game for him or herself. This coach was developed as a robust, friendly and intelligent tutor that could work well in the home and classroom.

Robot Sensing

Giving robots sensory capabilities is an important part of the effort to endow robots with intelligence. A smart robot must find its way independently and cope with the unexpected. It can only begin to do this if it can sense the distance to any surrounding obstacles, feel if it is touching something, or analyze pictures taken with an onboard camera. Many of the historic robots acquired by the Museum and on display in the exhibit's Smart Machines Theater were built as experiments, allowing researchers to explore how a robot can gather and make good use of sensory data.

The Museum visitor can experiment with four robot senses: vision, hearing, touch and sonar. Human vision is so sophisticated that we hardly appreciate its complexity. For example, just consider how we can instantly recognize everyday objects, such as a tree or cat, even though no two examples look alike in detail. Our vision relies on a great deal of knowledge about the world and about what we expect to see. By contrast, machines rely mainly on the details of the actual image, analyzing it first to find edges, and identifying objects by their outlines. This ap- proach makes machines better at matching complicated abstract patterns, such as fingerprints. Part of a fingerprint recognition system used by police departments all over the world is on display. Visitors try to match a fingerprint on the screen with one of several prints displayed on the wall from famous criminals. The computer then shows how it would make the match, using the points where ridges start or fork to classify the pattern accurately.

Speech recognition systems can give computers a reasonable sense of hearing, particularly if the machine has been trained by the speaker. Visitors can use several systems, including one that can be trained to respond to the visitor's voice. Even after training, computer speech recognition is limited to a few thou- sand words at most and generally requires the speaker to pause briefly between each word. In both speech recognition and vision, computers have yet to match the ability of a two-year old child.

A sense of touch is needed by a robot hand when it tries to grasp a delicate object. A pressure sensitive pad mounted on the robot gripper can gauge the amount of pressure being applied. Visitors see the pressure of their fingers on a pad displayed as an array of colors on a screen.

Finally, visitors can try out a sense that humans do not have - sonar. Robots use sonar to gauge the distance to surrounding walls and obstacles. The sensor emits pulses of extremely high-pitched sound, which reflect off an object and are picked up by the detector. The sound's round trip travel time indicates the distance to the object. In the exhibit, a ceiling mounted sensor measures a visitor's height by bouncing a signal off the top of the head.

Mobile Robots

In addition to its sensing ability, an intelligent, independent robot must have a suitable drive system and should be able to form and achieve goals. All the mobile robots on display in the exhibit are equipped with a drive system. Most have some form of sensing, but only Shakey seriously attempted the last and hardest requirement of forming plans and reasoning.

A mobile robot from Real World Interfaces roams around a cage, using sonar to sense and map the walls and obstacles. Visitors can try to override the robot's good sense by controlling its movement with a joystick, but it will never let itself collide with a wall. In addition, about 25 robot toys are on display and can be tried out by visitors. Most have wheels, but several can walk; some have bump sensors, or respond to claps or squeezing.

An application mobile robots have already found is that of night watchman. The gallery's Sentry robot by Denning Mobile Robotics can carry TV cameras, infrared sensors and microphones to detect an intruder. The information it collects is radioed to a security office. Microwave beacons supplement the Sentry's onboard sonar, enabling it to patrol a path hundreds of feet long for hours on end without ever losing an exact knowledge of its position. In the exhibit, the Sentry patrols a short path, avoiding obstacles in its way. Its TV camera relays signals to another robot, the Hubot, whose onboard TV monitor displays the picture.

Robot Arms

Robot arms and hands attempt to replicate aspects of human manual dexterity. Arms are by far the most common type of robot. They perform a wide range of industrial tasks, from the tiny movements for assembling a wristwatch to the large powerful movements required to stack heavy cartons. In the exhibit, the real industrial arms are shown on video, and smaller, educational arms are operated by visitors.

Two robot hands are on display: the five-fingered Tomovic hand attached to the tentacle arm pictured on the front cover, and a three-fingered soft gripper from Shigeo Hirose at the Tokyo Institute of Technology.

An ingenious way to achieve responsive compliance was invented at the Draper Laboratories. Their system uses an arrangement of springs that greatly eases tasks such as putting a peg into a tightly fitting hole. With a stiff wrist, a robot would jam the peg and only make it worse by pushing harder. With the compliant wrist, however, the peg finds its way into the hole smoothly. Visitors can use a compliant wrist to try this out for themselves.

A major thrust of industrial development is to tighten the link between the design and manufacture of a product. Using a computer-aided design system, an industrial designer can create a product and then send instructions for making that product directly to a numerically controlled tool or to a robot. Visitors can experiment with this process by designing a log cabin made of lincoln logs. When the design is complete, the cabin is constructed automatically by a pair of simulated robots on a screen. Real robots would need to be guided by a vision system to ensure that the logs were positioned accurately. This is demonstrated in an adjacent display in which a vision system guides a robot arm that assembles a toy boat from its parts. Both these displays were provided by the University of Lowell's Center for Productivity Enhancement.

The Future

The exhibit can be readily updated as new items become available. A large industrial arm has already been offered to us by Cincinatti Milacron, and we hope to be able to demonstrate an industrial application. We welcome suggestions from our members and visitors!

A Historical Timeline of Artificial Intelligence and Robotics

Gwen Bell and Leah Hutten

The Smart Machines exhibition has two historical components. A timeline, on display at the entrance to the exhibit, chronicles the major milestones to 1979. The Robot Theatre displays a collection of historic robots through the early 1980s. This article is intended as a synthesis of these two exhibits

Precursors

- **1738**
  Jacques de Vaucanson builds a mechanical duck to tour and raise money for the inventor's experiments for creating life artificially. The copper duck quacks, bathes, drinks water, eats grain, digests it, and voids.

- **1818**
  The book, Frankenstein, by Mary Shelley, includes the first description of creating a manmade being, who becomes a fearful monster.

- **1900**
  At the Paris World's Fair, Torres y Quevedo demonstrates an electromechanical machine that can play selected chess end games .

- **1920**
  Karel Capek writes the play R. U. R. (Ross='s Universal Robots) in which robots are produced by an Englishman named Rossum. The name, Rossum, is derived from the Czech word for reason, while robot is a Czech word for worker. The popularity of the play led to the widespread adoption of the word robot.

- **1942**
  Isaac Asimov publishes "Runaround" in the March issue of Astounding, in which he introduces the Three Laws of Robotics.

  This is the first known use of the term "robotics."

- **1943**
  Warren McCulloch and Walter Pitts propose that the behavior of the brain can be treated as a network of neurons that behave like on-off switches.

- **1947**
  Only a year after the completion of ENIAC, the first electronic computer, Arthur Samuel proposes to build a computer to play checkers.

- **1948**
  Norbert Wiener coins the term cybernetics, a philosophical perspective for describing interacting systems in terms of exchange of information.

- **1949**
  The Debate Begins: Can Machines Think?

  On June 9, at Manchester University's Lister Oration, British brain surgeon Sir Geoffrey Jefferson states, "Not until a machine can write a sonnet or compose a concerto because of thoughts and emotions felt, and not by the chance fall of symbols, could we agree that machine equals brain that is, not only write it but know that it had written it. No mechanism could feel (and not merely artificially signal, am easy contrivance) pleasure at its successes, grief when its valves fuse, be warmed by flattery, be made miserable by its mistakes, be charmed by sex, be angry or miserable when it cannot get what it wants."

  On June 11, The London Times quotes the mathematician Alan Turing, "I do not see why it (the machine) should not enter any one of the fields normally covered by the human intellect, and eventually compete on equal terms. I do not think you cam even draw the line about sonnets, though the comparison is perhaps a little bit unfair because a sonnet written by a machine will be better appreciated by another machine."

  In New York, Claude Shannon's paper to the Institute of Radio Engineers proposes two computer chess strategies that are still in use. The first is to look at all the choices up to a fixed depth and the second is to look at a selected few to greater depth.

In the 1950s robots and artificial intelligence (A.I.) start evolving along separate tracks.

- **1951**
  Turing creates a standard test to answer: "Can machines think?" If a computer, on the basis of written replies to questions, could not be distinguished from a human respondent, then it must be "thinking,"

- **1954**
  George C. Devol, Jr., applies for the first US patent for an industrial robot. He calls it "unimation" for short.

- **1956**
  John McCarthy of Dartmouth convenesthe Dartmouth Summer Research Project on Artificial Intelligence, marking the birth of the field.

  Herbert Simon, Allen Newell, and J.C. Shaw write "Logic Theorist," one of the earliest programs to investigate the use of heuristics in problem solving.

- **1957**
  John McCarthy and Marvin Minsky found the first artificial intelligence laboratory at M.I.T.

  Simon, Newell and Shaw write the pioneering, "General Problem Solver." It is the first program that solves a problem that it hadn't been specially programmed to solve.

- **1958**
  Simon, Newell and Shaw design and use the first list processing program, IPL-V.

- **1959**
  McCarthy creates LISP. Unlike other current programming languages, LISP is designed to work with English words and phrases. A key feature is that the data and programs are simply lists in parentheses, allowing a program to treat another program - or itself - as data. This characteristic greatly eases the kind of programming that attempts to model human thought.

  Frank Rosenblatt invents an ingenious evidence-weighing machine called a "Perception." It is supposed to recognize patterns by their parts without regard to their relationships.

In the 1960s, the Department of Defense Advanced Research Project Agency(DARPA) provides largescale funds for artificial intelligence research at Carnegie-Mellon University, Massachusetts Institute of Technology and Stanford University.

Joe Engelberger, the entrepreneur, works tirelessly to get Joseph Devol's ideas for industrial robots into use. Engelberger eventually eams the title "Father of Robotics. "

- **1961**
  James Slagle writes a Symbolic Automatic Integrator (SAINT) to solve elementary symbolic integration problems at the level of a good college freshman.

  SAD-SAM (Syntactic Appraiser and Diagrammer Semantic Analyzing Machine) is programmed by Robert Lindsay at Car negie Institute of Technology. The program accepts English sentences about kinship relations, builds a data base and answers questions about the facts it has stored.

  SAD-SAM INPUT: John is Mary's son. SAD-SAM OUTPUT: Mary's brother is John's uncle; Mary's mother is John's grandmother, etc.

- **1962**
  Engelberger founds Unimation, the first industrial robot company. The Unimate Mark II robot welcomes visitors into the Museum's Smart Machines Gallery.

  Samuel's checkers program, which has the ability to learn from its mistakes, plays at the masters level.

- **1963**
  McCarthy leaves M.I.T, and founds Stanford University's artificial intelligence laboratory.

  At Rancho Los Amigos Hospital an orthotic arm is designed to aid a paralyzed person.

  Stanford University modifies the Rancho Arm to be controlled by a computer.

  Photo Dan McCoy, Rainbow. On loan from Stanford University

- **1965**
  A five fingered aluminum prosthetic hand is developed by Rajko Tomovic at The University of Belgrade.

  The PDP-6 becomes the workhorse machine for the artificial intelligence community. The PDP-6's architecture is particularly suited for running LISP programs.

  Edward Feigenbaum and Bruce Buchanan conceptualize expert systems and start the Dendral project.

  Hubert Dreyfus' paper "Alchemy and Artificial Intelligence," is published by The Rand Corporation. His assertion that "Even though machines can perform intelligent tasks, the evidence against their ever becoming able to be really, humanly intelligent, is overwhelming," leads to debates and research that continue into the 1980s.

  Scientists at Johns Hopkins University create the Beast (Mod II) as an experiment to replicate animal behavior in a robot. When it gets "hungry" (low batteries), it uses sonar and a photocell array to find "food" (wall power outlets). Pressure-sensitive switches perform the fine guiding of its prongs into the wall socket.

  Victor Scheinman and Larry Leifer build the "Orm," Norwegian for snake. This robot arm moves by selectively inflating groups of its 28 air sacks sandwiched between seven metal disks. Its design is later abandoned because its movements could not be repeated accurately.

  The Stanford Cart is built at the A. I. Lab to simulate a remotely controlled Moon rover.

- **1966**
  The program ELIZA, written by Joe Weizenbaum at M. I. T., tries to assume the role of a nondirective therapist. It turns sentences into questions and responds to key words about feelings and family.

  Richard Greenblatt's MacHac is the first machine to achieve a Class C rating in the National Chess Association (approaching the level of a serious weekend amateur player).

- **1967**
  Television cameras controlled by a remote computer are added to the Stanford Cart, permitting it to follow a white line on a road.

- **1968**
  Engelberger travels to Japan and grants Kawasaki the right to build Unimates in exchange for royalties. These are the first robots built in Japan.

Bruce Buchanan and Edward Feigenbaum, working with Chemist card Nobel Laureate Joshua Lederberg, complete DENDRAL, an expert system for generating explanatory hypotheses in organic chemistry.

Marvin Minsky constructs the 12 jointed Tentacle Arm, which can reach around obstacles. A PDP-6 computer is used for control and hydraulic fluids for power.

Seymour Papert writes "The Artificial Intelligence of Hubert L. Dreyfus: A Budget of Falacies." In it, he states, "It is cowardice to ... assure us that the computer is barred by its finite number of states from encroaching further into areas of activity ... (regarded) as 'uniquely human'."

- **1969**
  Shakey, the first integrated robot system equipped with a TV camera and other sensors, slowly roams through the roorns of The Stanford Research Institute, guided by the remote radio control of an SDS-940 computer.

The Original Stanford Arm, the first successful electrically powered computer-controlled robot arm, is constructed by Victor Scheinmam. It is used to develop industrial assembly techniques for robots.	

In the 1970s, A.I. is recognized as a computer science discipline, and industrial robots are put to work in factories around the world.

- **1970**
  200 people attend the first meeting of the International Joint Conference on Artificial Intelligence (IJCAI).

  Terry Winograd integrates natural language understanding and knowledge about a world of table top blocks in SHRDLU, written for his doctoral thesis at M.I.T.

- **1971**
  France installs its first industrial robot, a Unimate, at Renault's R-5 plant to build LeCar.

  Stanford Research Institute gives Shakey the ability to reason about its actions. Shakey radios information from its sonar and bump sensors to a room-sized computer (DEC PDP-10 and PDP-15), which sends back commands to make Shakey move. The computer spends about half am hour to move Shakey one meter.

  DARPA funds a $15 million, fiveyear research program to achieve a breakthrough in speech understanding.

- **1972**
  At the University of Aix-Marseille, Alain Colmerauer develops the use of formal logic as a programming language, PROLOG.

  LUNAR, a natural language information retrieval system, is completed by Woods, Kaplan, and NashWebber at Bolt, Beranek and Newman. LUNAR helps geologists access, compare and evaluate chemical-analysis data on moon rock and soil composition from the Apollo 11 mission.

- **1973**
  Yorick Wilks writes the first acceptable language translation program, which produces respectable French from small English paragraphs.

- **1974**
  The first commercially available mini-computer controlled robot, T3, is produced by Cincinnati Milacron.

  The first World Computer Chess Tournament is held.

CONS, the first computer built to optimize LISP, is completed by Tom Knight at M.I.T.'s A. I. Lab. It is the precursor of CADR and the commercial machines built at LMI and Symbolics.

- **1975**
  MARGIE (Meaning Analysis, Response Generation, and Inference in English) is developed by Roger Schank and his students at the Stanford A. I. Laboratory.

  Minsky develops the concept of frames as a convenient way to represent specific objects or concepts. Each frame consists of a name and a series of slots that describe the object's or concept's attributes.

  Unimation has its first profitable year.

- **1976**
  The DARPA speech goals are met by the HEARSAY speech program developed at Carnegie-Mellon University under the direction of Raj Reddy. It beats DARPA's goal of understanding 90% of ordinary continuous speech using a vocabulary of 1000 words.

- **1977**
  Hans Moravec equips the Stanford Cart with stereo vision. A television camera that moves along a rail takes pictures of a given scene from several different angles, enabling the Cart to find the distance to obstacles in its path.

  In the USA, Robert McGhee develops a hexapod walking machine controlled by a digital computer. In the USSR, scientists develop a hexapod walker controlled by a hybrid (analog and digital) computer.

  EMYCIN developed by William Von Melle, Edward Shortliffe, Bruce Buchanan, and Edward Feigenbaum is the first expert system "shell." A shell is a program that provides the framework for developing an expert system. The user supplies his own rules to build an expert system in the subject of his choice.

  The programs SAM (Script Applier Mechanism) and PAM (Plan Applier Mechanism) are developed by Roger Schank, Robert Abelson and their students at Yale University. SAM and PAM demonstrate the understanding of stories by using scripts and plans.

  The Jet Propulsion Laboratory builds two Rover prototypes designed to explore Mars. To stay upright, the Hardware Prototype has caterpillar tracks mounted on flexible legs.

  The Software Prototype has both sensing ability and intelligence.

- **1978**
  The Mars Rover project is cancelled because NASA opts for a manned space program.

  GM unveils its production line, which uses a programmable universal machine for assembly (PUMA) system based on the Scheinman arm.

  Hans Berliner's backgammon program wins the world championship.

  Consight-I, by Steven Holland, Lothar Rossol and Mitchel Ward, is able to identify and sort randomly oriented parts on a moving factory conveyor belt. When the parts move under two converging light beams, the beams are split in two. This pattern is detected by a computer connnected to a television camera. Consight-I consists of a Vicarm robot arm controlled by a PDP 11/45 computer. Commerical versions use an arm by Cincinatti Milacron.

- **1979**
  After seven years of research, Moravec's refined Stanford Cart successfully traverses, without human intervention, a room strewn with chairs

- **1981**
  Avatar represents a breed of personal home robots that evolved following the microcomputer revolution in the early 1980s. This robot can move without bumping into things, talk, and handle objects with its arm.

- **1981**
  The first direct drive (DD) arm by Takeo Kanade served as the prototype for DD arms used in industry today. The electric motors housed inside the joints eliminate the need for chains or tendons used in earlier robots. DD arms are fast and accurate because they minimize friction and backlash.

- **1981**
  One of three of Shigeo Hirose's robots at the museum, the quadruped can perform a complicated task such as "feeling its way" up stairs of varying heights. It has contact sensors on the sides and bottom of its feet. When these are touched, the quadruped responds with animal-like reflexes. Each leg contains an elegant mechanical device that translates small motor movements inside the body into larger movements of the legs.

- **1983**

Odex is the first commercially available walking robot. It can work in dangerous places inaccessible to vehicles with wheels. These include radioactive zones in nuclear power stations, military battlefields, and underground mines. Its legs can also serve as arms for lifting and moving objects.	

  Odex is the first commercially available walking robot. It can work in dangerous places inaccessible to vehicles with wheels. These include radioactive zones in nuclear power stations, military battlefields, and underground mines. Its legs can also serve as arms for lifting and moving objects.

- **1985**
  Underwater rovers explore the ocean depths under remote control. The famous Titanic wreck was explored by a large rover called Argo, but most underwater rovers are used for more routine inspection tasks. The Sea Rover, designed by Christopher Nicholson, can dive to depths of up to 120 meters and travel at 1.5 knots while relaying color video pictures from under the sea.

BIPER-3, designed by Hirofumi Miura and Isao Shimoyama in 1981, was the first legged machine to balance itself dynamically. Like a person, its gait relies on its own forward momentum. It has stilt-like legs and uses its hips to pick up its feet. This gives the machine a pronounced shuffling gait like Charlie Chaplin's stiffkneed walk. BIPER-3 can walk forward, backward, or sideways. On loan from the University of Tokyo, Tokyo, Japan	

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Highlights from

The Computer Museum Report

Volume 21 ---- Winter 1987/88

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Joint Collecting Agreement

We have signed a collaborative agreement with the Smithsonian Institution, National Museum of American History, which promises to enhance the computing collections of both institutions.

"This is the first such formal joint collecting agreement the Smithsonian has made with a museum of the stature of The Computer Museum," said Dr. Arthur Molella, chairman of the Department of the History of Science and Technology, of the Smithsonian's National Museum of American History and a member of The Computer Museum's Board of Directors. He further explained, "The field is so large and there is so much to do that it's necessary for us to make agreements in important collecting fields with the leading specialized museums."

The joint arrangement with the Division of Computers, Information, and Society of the National Museum of American History is broad in scope, affecting historical research, preservation and exhibitry. We will cooperate in creating a common catalog and database of our collections. This is being carried out by a group composed of David Allison and Jon Eklund from the National Museum of American History and Gwen Bell and Lynn Hall from The Computer Museum.

The common goal in our collecting agreement is to make sure that all the important artifacts are preserved. Considering that computers are now entering their fifth generation and that the classes range from supercomputers to personal computers, the amount of material worth saving is growing. Cooperative collecting is essential for preservation.

The Scientific Instrument Commission of the Union Internationale d'Histoire et de Philosophie des Sciences is also cooperating in the effort to develop a complete listing of computer artifacts held around the world. While the collection of The Computer Museum is international, many national and specialized museums preserve many significant machines from their regions. For example, The Science Museum, Kensington, has much of the known Babbage equipment and The Deutsches Museum, Munich, has a collection of the machines built by Konrad Zuse. The Computer Museum is proud to have the NEAC 2201, one of the first transistorized computers in Japan built by NEC, components of EDSAC, Maurice Wilkes' Cambridge University computer that is the first fully operational stored program machine, and other non-U. S. computers. One of the goals of The Computer Museum is to show that computer innovations are not unique to one country, to one company, or to any one institution.

Saving the history does not just mean collecting artifacts. For each artifact, a technical file is also needed. Such material includes manuals, notebooks, photographs, and other accounts of the development and use of the machine.

This report lists new acquisitions to the collections of the Museum. The listing illustrates the diversity of the collection. We have chosen to feature some ephemera on the cover, because this material is often thrown out or thought to have little value. On the contrary, ephemera are important because they can quickly evoke the spirit of an era. Don't throw out your memorabilia. Send it to us. Do it all at once, or one at a time. Several times a year, we receive a small envelope from Phil Dorn - it always has a surprise spec card from an early computer or some other piece of ephemera. When Lynn Hall, the registrar and I open it, we generally smile the rest of the day. You too can make our days happy.

Gwen Bell
Founding President

The Early History of LEO: The First Data Processing Computer

John M.M. Pinkerton

John Pinkerton was the chief architect of LEO, which stood for Lyons Electronic Office. LEO, the world's first commercial data processing computer, is a direct descendant of the architecture outlined in draft EDVAC Report via the Maurice Wilkes' EDSAC. LEO I was being used for payroll and office data processing in early 1954, prior to similar use by GE of their UNIVAC 1.

John Pinkerton tells his own story, that of a young physics graduate of Cambridge, who joined The Lyons Company and was inspired by Comptrollers John R.M. Simmons (who died in 1985) and T. Raymond Thompson (who died in 1972) to build the first data processing computer. G.B.

This is an abstract of a talk given by John Pinkerton at The Computer Museum on October 4, 1987. A paper on which this talk is based is copyrighted by John MM. Pinkerton.

John M. M. Pinkerton and Gwen Bell at the talk. Pinkerton presented the Museum with a marketing film to sell LEO II computers that was made by Lyons in 1957.

The Lyons Company

How did it happen that J. Lyons & Company Limited, a wholesale food and catering business, came to build a computer for its own use and then go into the computer business?

In the 1890s, the Salmon and Gluckstein families started a business at Cadby Hall in West London to cater for functions at the Olympian exhibition halls next door. By the beginning of World War II, Lyons had a high reputation for efficiency with the general public. They ran a variety of wholesale food businesses distributing tea and coffee, ice cream, bread and cakes, as well as other lines throughout the UK. Lyons did not believe in using wholesalers but sold and delivered directly to twenty or thirty thousand small retail shops. They also had a chain of about 150 tea shops, four or five large hotels, various restaurants, and an outdoor catering division. They employed 30,000 people. All this meant routine accounting for a vast number of small transactions with clerical efficiency since margins were small.

In the early twenties, the need for effective methods of accounting was recognised and resulted in the recruitment of a young mathematics graduate from Cambridge, John R. M. Simmons. A few years later he recruited another Cambridge mathematician, T. Raymond Thompson. By the mid-thirties they had rationalized the Lyons office practice and brought it under their management. In LEO and the Managers (1962), Simmons wrote, "...the curse of routine clerical work is that without exercising the intellect, it demands accuracy and concentration . ...(He was) looking forward to the day when machines would be invented which would be capable of doing all this work automatically."

By the thirties, Simmons and Thompson were not only studying the accounting and calculating machines on the market but using some in intensively unorthodox ways. For instance, they were pioneers in the use of the Kodak Recordak camera for processing bakery orders. Punched card systems were not generally favored. Lyops believed that the rationalisation of clerical procedures that was needed to transfer work to cards would not prove to save costs.

When I joined Lyons in 1949, Simmons was Chief Comptroller and Thompson was Chief Assistant Comptroller. They were in charge of some 2,000 clerical staff who worked in large open plan rooms with 200 clerks carrying out routine payroll calculations, order processing or invoice passing. I found the atmosphere in the clerical department was one of high seriousness of purpose and dedicated loyalty on the part of the staff. Systematic grading of clerical jobs had been pioneered in Lyons' offices and rewards and promotion were strictly related to merit, which was regularly reviewed.

Simmons was totally dedicated to management and especially to the collection and application of management information using the computer. This came out clearly in his second book: The Management of Change (1970).

Thompson joined Cadby Hall in 1928, after working in a Liverpool department store. He had the quickest intelligence of anyone I ever met. Much of the inspiration for the hardware development as well as the software of the LEO project came from him. He could quickly visualize ways to organize anything from a complex clerical task to a language compiler down to the finest detail. He maintained the enthusiasm and set the intellectual and management tone of the Leo project from its beginning in 1947 to the merger with English Electric in 1963.

The Birth of LEO

In 1947, Lyons sent Thompson and Oliver Standingford to the USA to investigate the "giant brains" that were then being reported in the British press. An introduction was obtained to meet Professor Goldstine at Princeton who was associated with the ENIAC and specifying the EDVAC. I heard Thompson's account of this meeting several times. It apparently lasted an hour or so. In the first half hour, Goldstine explained to Thompson the principles of the stored program computer. In the second half hour, Thompson explained to Goldstine just how the computer could be employed on routine clerical work, such as payroll and invoicing.

Ironically in the USA, they learned about Maurice Wilkes' EDSAC project underway at Cambridge University. They lost no time in going to Cambridge on returning to the UK. After seeing Wilkes' project, Thompson told me he was impressed by the squareness of the pulses he saw on an oscilloscope in the lab (even though he had no knowledge of electronics). Thompson and Standingford formed a favorable impression of Wilkes' work reported for the Lyons Board. Only a fragment of this has been preserved: "We believe that they have been able to get a glimpse of a development which will, in a few years time, have a profound effect on the way in which clerical work (at least) is performed. Here, for the first time there is a possibility of a machine which will be able to cope, at almost incredible speed, with any variation of clerical procedure, provided the conditions which govern the variations can be pre-determined. What effect such a machine could have on the semi- repetitive work of the office needs only the slightest effort of imagination. The possible saving from such a machine should be at least £50,000 a year. The capital cost would be of the order of £100,000.

"We feel therefore that the Company might well wish to take a lead in the development of the machine and, indeed, unless organizations such as ours, namely the potential users, are prepared to do so, the time at which they become commercially available may be unnecessarily postponed for many years."

In November 1947, the Board agreed to contribute £2,500 to the cost of the EDSAC and to lend Ernest Lenaerts to Wilkes for six months, which turned out to be nearer a year. Lenaerts, who had worked for Lyons for several years, was employed in electronic engineering during his war service. In return, Wilkes agreed to give Lyons whatever details of the EDSAC design they might need to build a machine for their own use. Lenaerts reported to Thompson on progress.

The EDSAC being built at Cambridge University Mathematical Laboratory. Maurice Wilkes is kneeling in the center behind the mercury delay lines.

During 1948 Lyons tried, and failed, to find a contractor to build a machine like the EDSAC. Later that year they decided in principle that when Wilkes' machine had been shown to work, they would build a version of it themselves. They therefore advertised for someone to take charge of the engineering and I applied for the job.

When the anonymous advertisement appeared I suspected it was from Lyons. I had returned to Cambridge after the war to work with Mr J. A. Ratckffe at the Cavendish Laboratory only 100 yards away from the Maths Lab where Wilkes worked. I wrote a thesis on ultrasonic absorption in liquids using a pulse method which, as it happened, was an ideal preparation for work on computers using delay lines for storage. I first met Wilkes as an undergraduate through the University Wireless Society. In the summer of 1948, Wilkes told me about Lyons' interest in building a computer.

In December 1948, I went for an all day interview at Lyons which was extremely impressive. Not only was I given an excellent lunch, but Mr G. W. Booth, the venerable but alert Director of the clerical department who was over 80 years old, carne out to interview me. He asked me if I thought I could make this machine work. I optimistically said I could, but added that as it needed several thousand valves, it would be difficult to make reliable, which naturally turned out to be correct. On December 18th, I got married and in mid January, 1949, I started to work for Lyons.

Construction of LEO I

Lyons decided to wait to start building their copy of EDSAC after it was demonstrated to work by computing a table of primes. In the meantime, I went to a Lyons training course given to their office supervisors and spent several weeks in Cambridge absorbing the design of EDSAC and its logic and circuit techniques. Ernest Lenaerts and I set up a small workshop to build a delay line and circulate pulses in it. We also tried some ideas for transmitting pulses over long leads because we thought LEO would be physically bigger than EDSAC.

In February 1949, I started discussions on how to deal with the input and output problems revealed by the payroll program. It was recognized that input data would typically fall into one of three categories: (1) current data reflecting events since the last run of the job, (2) data brought forward from that run and (3) semi-permanent data not requiring to be repunched for each run. Similarly results would fall into at least two categories: (1) results to be printed and acted on (e.g., wages to be paid) and (2) results to be carried forward.

The EDSAC being built at Cambridge University Mathematical Laboratory. Maurice Wilkes is kneeling in the center behind the mercury delay lines.

We decided that LEO needed multiple channels for both input and output, to be fitted with buffers that could be read in a single operation and were large enough to hold all the data items of a given kind, e.g., one person on the payroll. We also decided that LEO needed means for converting and reconverting data and results automatically in each channel, rather than using subroutines within the machine. The first of these decisions turned out to be excellent but the second was bad in execution and probably in principle. Once EDSAC began to work, events moved fast at Cadby Hall. A large room in the office block was allocated, staff were transferred from other departments or hired from outside, and Lyons excellent drawing office got to work drawing up racks and chassis to carry the circuits. A contractor was appointed to build the units, and a revised design of the EDSAC batteries of ultrasonic delay lines was drawn up making full allowance for engineering tolerances.

The overall orgmization of LEO I as it was built.

Putting LEO to work From the start Lyons believed that their own staff should create programs for LEO which would be suitable for the work of their offices. In 1950, David Caminer who had been in charge of Lyons Systems Research Office was appointed to take charge of all LEO programming. Payroll was to be the first main routine task. Since a breakdown in the middle of a two hour job could be serious, the concept of putting out restart totals at the end of each department in the payroll was established early on.

Handmarked documents at J. Lyons & Company Ltd. to be automatically read and transferred to punched paper tape by LEO in the early sixties.

Punched card machines were used for all channels, except those carrying current input data, for which we chose punched tape. Binary, not decimal numbers, were punched into the cards as a compact method of carrying forward results from one run of a job to form the data for the next.

We estimated that doing the conversions by subroutines would take up 90% of the time of LEO I. But the conversion and reconversion problems were solved when Lenaerts recognised that if the binary values of 10, 100, 1,000 and so on were stored in a matrix of the new germanium diodes, then the control circuits for multiplication and division taken over from EDSAC could be adapted to control the two conversion operations. They took no more than 10% of LEO's time, an acceptable overhead. About 1,000 new germanium diodes were used, accomplishing a task that would have been impractical with hot cathode diodes used elsewhere in LEO.

In 1953, when the machine was ready for use, the entire clerical staff of Lyons, numbering more than 2,000, was brought to Cadby Hall in batches of 30 to see a demonstration of LEO. Within six months, LEO produced part of the payroll for the Ford Motor Company at Dagenham. Early in 1954, LEO started doing the Cadby Hall payroll and other jobs followed rapidly, including bakery sales and tea shop orders.

LEO Lives On ...

Lyons saw LEO I as a considerable success and it remained in service until 1954. They invested in a design of an improved model for small scale production and sale, LEO Mark II, which ran about three times faster than LEO I. Eleven LEO II's were built - all of them slightly different.

Before the end of the fifties, it became obvious that a parallel transistorized machine was feasible and we embarked on LEO III. This was a 40-bit parallel machine of advanced architecture incorporating (as we later found out) many ideas also used in the IBM 360 series. Besides the multiple, buffered I/O channels provided by LEO I and II, it had multi-radix, as well as floating point arithmetic, extremely effective checking of data recorded on tape, direct input and output to and from main store (DMA) and 4 protection tag bits to each word in store allowing multitasking with up to 15 jobs. It was, I believe, also the first machine using microprogramming to go into production anywhere in the world.

About 150 LEO III's were built and sold. However, the capital demands of a growing business persuaded Lyons in 1963 to merge the computer department with English Electric. Later they sold their half share of the joint company to English Electric. While no LEO III's remain in use, a few System 4 machines from English Electric and 2900 series models from ICL have micro coded implementations of the LEO III instruction set, thus allowing one valued customer to continue to use an interlocked suite of programmes originally written for LEO III in the midsixties.

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Highlights from

The Computer Museum Report

Volume 22 ---- Spring 1988

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The Beginnings of Computer Games

David Ahl

This is adapted from a keynote talk at The Computer Museum's Computer Games Weekend, November 6-8, 1987. David Ahl is the founder of Creative Computing, the first magazine that focused on all the uses of the personal computer from games to science and home business.

What Makes a Good Computer Game?
It takes many elements on several levels, skillfully combined, to make a good computer game. For example, good computer games are easy to learn, but not easy to beat. They are a challenge to expert players, but accessible to novices. They have elements of fantasy, but do not totally abandon reality. They are fun and keep us coming back for more.

One way of thinking of the world of computer games is as a Venn diagram of games, puzzles, and simulations (Figure 1). Simulations are representations of real-world processes such as a journey over the Oregon Trail, the landing of a lunar capsule, or a game of blackjack. Puzzles are problems with a baffling quality or great intricacy that require substantial mental ingenuity to solve such as the Chinese ring problem, the Lady and the Tiger, or even tic-tac-toe. And games, we know, can range from fantasy to shoot 'em up to Pacman.

Although thousands of computer games have come and gone, only a handful, such as Spacewar!, will be considered classics. I believe, in general, these classics will fall in the middle area of the Venn diagram. They will have some elements of fantasy, of simulation of realworld processes and people, and of puzzlement. While graphics may add to the visual presentation, they aren't really necessary. For example, the text adventure games from Infocom and others have elements of fantasy, simulation, and puzzlement which provide many layers of interest and challenge to a wide variety of players.

The First Computer Game.
Not only are we celebrating the twentyfifth anniversary of Spacewar!, but in 1987, the thirtieth anniversary of computer games themselves.

The first computer game was developed in 1957 by Willy Higinbotham at Brookhaven National Laboratory. This is not widely known, and has not been widely written up, but I do know that some of the current games writers saw it and were influenced by it.

In the late fifties, people thought of computers as magic. At Brookhaven National Laboratories, one of the centers of atomic energy research, tours were held to educate the general public. Higinbotham noted that the visitors really couldn't relate to any of the machinery. He took a five-inch oscilloscope and devised a game. He used potentiometers to adjust the angle of little paddles in the bottom two corners. He put a line that represented a net in the middle and had a blip that bounced back and forth over the net, thus devising a simple game of tennis. The player adjusted the angle of the paddle to hit the ball higher or lower. You actually couldn't see the paddles but had to guess, based on turning the nobs of the potentiometer. One nice feature was that you always hit the ball if it came over the net. If you hit it into the net or over your head you lost. It wasn't a tremendously challenging game, but in 1957, it represented something that was "neat" and fun. I was a senior in high school, saw it and thought that it was spectacular. That was the first computer game even though it involved some special electronics and a mainframe with the capability of a small Atari today.

David Ahl brings fun and computing together with his books and magazines on computer gaming.

The First Widely Used Computer Simulation.
In the early sixties, the faculty of the business school at Carnegie started to build a monstrous business simulation known simply as "the management game," which in a form is still being used. The concept was set down in the late '50s to devise a simulation of the detergent industry, to allow students to take the role of companies and compete against each other, with a week equalling a year and play continuing for twenty years. What started as a simple marketing game then became more and more complex as other modules were added. In 1961 and '62, as the concept developed, additional modules were made for different areas such as research and production. A major challenge was getting these all to work with each other. It started to become a truly interactive simulation even though we had to feed the machine 3000 punched cards a week to run the model.

The original game was written in a language called GATE on a Bendix G-15 computer. In my second year at the Graduate School of Industrial Administration, I had a job to convert the program into the new language called FORTRAN. (I got the job because at the time I was one of the few people who knew FORTRAN, hawing learned it working at Grumman Aircraft on an IBM 704 simulating the cockpit controls of jet fighters.)

The PDP-8 Educational Simulations.
In 1969 when I joined DEC there really wasn't an educational market. The PDP-8s spoke machine language and FOCAL, an interactive language modelled on ALGOL written at DEC by Rick Merrill. It was a very interesting and powerful language that, in hindsight, could have been the generic language if DEC had made it widely available. Then BASIC would not have had a chance.

Rick Merrill also developed some simulation games - which is what interacting with a computer is all about. In one of these, Hammurabi, students manage a little city-state where they buy and sell land, feed their subjects, protect grain warehouses from rats, save grain for planting next year's crop, and deal with lots of little interacting variables. We fit both FOCAL and the program into the 4K memory available on the PDP-8. The original program was about 700 bytes. Since the world was not beating a path to DEC's door to buy FOCAL machines, we contracted with others to write BASIC for the PDP-8.

The BASIC Interpreter for a stand-alone $8500 4K PDP-8 with a teletype Model 33 used 3.6K of the memory. This left 400 bytes for the program. One of the first programs we managed to jam into this little machine was Hammurabi, which was soon followed by Lunar Lander - a game derivative of Spacewar!.

Level two of selling machines to schools was to sell time-shared systems. But these were hard to explain so we developed a demonstration. When we brought this to the Brockton School System they wanted to schedule it in the auditorium so that the citizens could come and approve this major expenditure for the school. The first problem was finding the nearest telephone and running a cord down the hallway to the auditorium. We brought our ASR 33 teletype and set it up onstage. A pamphlet explaining a scenario of interactions on Hammurabi was distributed to the audience. Then Jim Bailey dialed the computer at Digital. He heard the tone and it spelled out, "Logon please." He entered an account number and it replied "Logon please." After several iterations he realized the system was down. Since he was up on the stage, Jim said, "Hammurabi has just come back and said, 'How much do you want to plant?' No matter what key he pressed, the computer replied "Logon please." When the demo was over, Jim crumpled up the paper and put it in his pocket. The bottom line: Brockton bought the $58,000 system - the first Time-Shared 8 in a New England school.

BASIC Computer Games.
At DEC there was little enthusiasm for publishing or distributing computer games. I was convinced they were of interest to our users. Because there was no support to publish BASIC Computer Games, I said 'I'll just do it. It won't cost anything. I'll type it in and do the layout myself.' It wound up costing DEC next to nothing and surprised everyone, even me, by selling out of the first printing of 10,000 in three months. In 1979, it became the first million selling computing book, in a version based on Microsoft BASIC under the Creative Computing label.

Its sequel, More Computer Games, did well, but the third book in the series, Big Computer Games, was printed but not distributed by Ziff Davis. My most recent book, Basic Computer Adventures published by Microsoft Press in 1986, has ten simulations of real adventures such as the travels of Marco Polo and Amelia Earhart with a few puzzles built in.

The First Personal Computing Magazine.
In November 1974, the first issue of Creative Computing carne out, devoted to the idea that computers cam be fun, not just business.

Nolan Bushnell's Second Game.
His first game was Computer Space, very much like Spacewar!. Unfortunately, it was distributed in the coin-op environment, bars and tavems, where the guy with a beer in one hand and a joystick in another wasn't up to learning the complexities of Spacewar!. Atari produced about 2,000 units but it never really was a big success.

Pong, a very simple and clever game, was a runaway hit. The story is that the first Pong game was put in a bar near Sunnyvale. Several days later Bushnell got a call asking him to take the game out because it didn't work. He took a look at the game and found that the breadpan of quarters was so full that the coins were jamming the mechanism. When the quarters were emptied once a day, it worked well. Eventually game designers built large coin receptacles eight inches deep under the whole machine.

The Video Computer System (VCS).

There was no one device more responsible for getting computers and games into people's homes than Atari's VCS (called the 2600 today). First announced in 1978, it sold by the millions and got people thinking about games and computers.

Computer Games Overdose.
By 1982, over 6 billion dollars of quarters per year were being put into the slots of coin-op, games alone, making that segment of the industry bigger than the rest of the sports industry combined, including football, the Indy 500, World Cup Soccer, and the Olympics. Hundreds of new games were announced and the life of a game went from over one year to less than two months. Less than one year later, boom turned to bust as manufacturers slashed prices and flooded the market with "me-too" products. Players got disgusted, and manufacturers, retailers and arcade operators started to go "belly up." The boom ended, but the games will go on forever.

Digital's conversational programming language, FOCAL, may have had great potential for the PDP-8, but was soon overshadowed by the popularity of BASIC.

The Beginnings of Rogue

Ken Arnold, the co-designer of Rogue, spoke about how he co-invented it less than ten years ago at Berkeley.

Since I'm less than thirty, I'm awed that I'm part of a history section. When I was first an undergraduate at Berkeley, the terminal room had ADM machines where you could only move the cursor down the page. This limited us to text games like Adventure and Rogue for the people who had ARPAnet accounts. Then came the dumb terminals where the cursor could move anywhere on the screen. That was really a boon to gaming. Then, people started to CRT hack ....that is, draw pictures on the screen and move them around. For about two months that seemed to be entertaining. Some people decided that this was the way to start writing games.

Ken Arnold and "Rogue," a program that took "a billion and a half dollars of compute time."

Rogue was developed by Michael Toy at Santa Cruz. He then came to Berkeley when the game had no real magic, such as potions. I had written some utilities to use the cursor on the terminal and so he came to me to help me. Having a lot of recommendations to change the game that I was now addicted to, we started to work together.

Michael set four goals that were unique at the time. First was to move away from text-only adventure games that are essentially mazes with the player as the mouse.

Second, Michael wanted to write a game that would be different for the player every time and interesting for the writer to play, the innovation was to use a random number generator to create new landscapes each time.

The third decision was to make a game that was impossible to win. Without a couple of forms of cheating, Rogue is only possible to win one out of every hundred thousand times.

Finally, Rogue was designed as a long game - taking two or three hours to play and thus it never became appropriate for an arcade.

Rogue is one of the most copied games; after royalties the second most sincere form of flattery. After three months at Berkeley, the game used more compute cycles than any other program. Two years after Michael and I released Rogue, we calculated on the back of an envelope that we had used about a billion and a half dollars of compute time in Silicon Valley.

Whirlwind's Genesis and Descendants

Whirlwind's Genesis and Descendants" was the theme of a symposium held at The Computer Museum October 18, 1987. This was part of a weekend reunion of the Whirlwind group organized by David Israel. The symposium was recorded at *the Museum and transcribed by Judy Clapp of the MITRE Corporation. Responsibility for the accuracy of the following adaptations of the talks belongs to The Computer Museum.*

Jay Forrester, T. K. Flnletter, and F. Wheeler Loomis visit the Whirlwind in November, 1951.

Whirlwind's Success

Jay Forrester

Jay Forrester is Germeshausen Professor of Management and Director of the Systems Dynamics Group at MIT. He was the leader of the Whirlwind group at MIT from the late forties until 1956.

Why did Whirlwind succeed? Why did more technical innovations out of Whirlwind persist into the present time than from any other of the early computers? The reason revolves around several things: the vision of the future direction of computing, a dedication to excellence, and the organizational environment.

Project Whirlwind's Future Vision
The vision in Whirlwind reached well beyond the uses of computation and hand-calculating machines at that time. Our work quickly became identified with the field of real-time control and reliability.

The dedication to real-time control started well before Whirlwind first operated. In October 1947, when we were still determining the logical structure of the machine, two reports were written in the MIT Computer Laboratory suggesting that the Navy could use digital computers as Combat Information Centers for co-ordinating an anti-submarine task force. This meant coordinating the car, the surface, and the subsurface pictures to get an understanding of the totality of what was going on.

Building Reliable Systems
Reliability was important because you can't go back and do things over again in military applications. In 1948, before Whirlwind operated, Karl Compton, then President of MIT and also Chairman of the Research and Development Board, asked that we prepare a memorandum for him on the future use of computers in the military. Bob Everett, Hugh Boyd, Harris Fahnestock and I took two or three weeks to answer that question. The report culminated in a chart listing vertically about twelve wide-ranging areas of computer use in the military, such as logistics, scientific computation, air defense and anti-ballistic missile control. On the other axis were 15 years from 1948 to 1963.

That report is quite an interesting document in historical perspective. At each intersection in each square in the table, we estimated the condition of the field at that time, how much money would be spent yearly in research, engineering and production, and what the condition of the field would be relative to those end uses 15 years into the future. These estimates were made when no high speed general purpose computer had yet functioned.

The estimates are percentage-wise as good as and maybe better than most estimates made today for the time and cost of the next computer to be put into production. This was because we paid a great deal of attention to tile political as well as the technological side. The cost estimates were arrived at by subdividing tasks to no more than 30 people working a calendar quarter and by deciding all the things that would have to be done. It was not necessarily correct in detail but it was a logically complete scenario including how long it would take for people to believe the results of the previous year, and how long it would take to get funding for the next step. The chart showed a total of $2 billion to be spent in research and development alone over the 15-year period. We went into a Navy conference with this. They thought the agenda involved whether we could have the next $100,000. There was a communication gap in that meeting.

Dedication to excellence
Many people in the Whirlwind group had had the World War II experience of going from theory through research to production design, then to manufacturing and into the battlefield, fixing their own mistakes at every stage. They understood how the decisions at the research stage really affect what happens later.

In my own early background, I had already started down that road, having grown up on a cattle ranch where you learned that if you did a sloppy job of fixing a tractor or a well, you would suffer the consequences very soon, have to do it over, and do it right. Part of the manifestation of that viewpoint showed up, of course, in our improving vacuum tubes. Until the 1950s, vacuum tubes primarily had been used for radios. Radio engineers were not concerned that the life of a vacuum tube was about 500 hours. But computer engineers, considering the use of many thousands of vacuum tubes, easily estimated that with such a short life, the machine would run no more than a few minutes between failures. One of the achievements of our group was determining the cause of failure of vacuum tubes. It turned out to be one thing. After removing that cause in the design, the life of vacuum tubes was increased, in one design step, from 500 hours to 100,000 hours or longer.

Excellence also meant thorough testing of components. We built a five-digit multiplier for the simple purpose of finding out whether an electronic device running continuously would be troublefree or not. There was uncertainty about things that people now thoroughly understand.

One important issue was our uncertainty about thermal noise. We didn't know if random spikes of thermally generated noise were big enough to trigger our robust computing circuits. We wondered whether thermal noise would intrude itself often enough to be devastating to accurate computation. To test for this, the five-digit multiplier was run continuously. Every multiplication was checked against a reference number. Sure enough, it didn't compute reliably all the time. It had a great tendency to make mistakes at 3 a.m. This was traced to the janitor in the building next door, who would start the freight elevator at about that time, upsetting the power circuits enough to produce a computation error. As a result, a rotating motor generator with enough inertia to carry through that kind of transient noise was installed on both Whirlwind and the SAGE Air Defense machines. It was an expensive solution but a very effective one.

A lot of time was spent writing test programs to find out the source of a failed component. Occasionally, a visitor was asked to go any place in the computer racks, pull out a vacuum tube and bring it back to the control desk. When he got back, the location of the empty socket would have been typed out by the machine itself. Finding solid, existing, reliable errors, like a tube pulled out of its socket, was not nearly good enough.

Other means of determining reliability were also essential, which we discovered in various ways. I remember one Saturday, during one of many annual reviews, our inquisitor asked, "What are you going to do about the electronic components that are drifting gradually and are on the edge of causing mistakes? Any little random fluctuation in power, or streetcars going by, will cause circuits to sometimes work and sometimes not." This was a very important and powerful question that, frankly, we had done nothing about. It was such a pointed question and obviously such an important one that I felt an immediate answer was essential. I said to him, "Well, we could lower the voltage on a tube and convert it from a marginal to a permanent failure and then it would be easy to find." He thought it was a good solution and so did we, so the next Monday we started designing it into the computer. The marginal checking system in Whirlwind carried over into the SAGE Air Defense system, adding another factor of ten to the reliability.

Many of you may not know the statistics on the SAGE system's s reliability. There were 30 or more SAGE Centers. Each building was about 160 feet square, four stories high, with upwards of 60,000 vacuum tubes in it. The question is: what percentage of the time do you think such a center would operate reliably? The answers I get from an audience today tend to run from 15% to 60 or 70%. They're really quite overwhelmed when they're told the historical statistics on the SAGE Air Defense system. It was installed in the late 1950s and operated for 25 years, until 1983. According to the data that Bob Everett was able to find, the uptime was 99.8%, which is really quite remarkable. In fact, you will have trouble finding anything equal to that, even when it has been designed with more modern components.

The attitude about the SAGE performance was that it must work reliably. To achieve high reliability, one must be a devout believer in Murphy's Laws - that if anything can go wrong it will. Every possible failure must be identified and forestalled. This attitude is the difference between something that is strikingly successful and disaster. In almost any major disaster, whether a technological or a social one, an ample number of people knew that it was likely to happen and knew in advance why it was going to happen. The information was there, and either they did not take any action, or they tried, and in the social circumstances of their environment, were not able to get any results. A warning is almost always present ahead of the trouble and the problem comes in getting any kind of action or acceptance of the threat.

The Organizational Environment

Another part of the success of the Whirlwind group came from the organizational environment within which we were operating. MIT in those days was a free enterprise society in which someone who had a vision and could raise the money for it could do what he thought was important.

The Leaders

Within our immediate environment, two people conspicuously stand out as having made it possible for us to operate the way we did. One was Nathaniel (Nat) Sage, Director of the Division of Industrial Cooperation, under which outside funding came into MIT and the other was Gordon S. Brown. In addition, there were two promoters, in the best sense of that word, people who shared the vision and who spent their time building up the outside constituency to support the work. These were Perry Crawford and George Valley.

Sage, a civil engineer by training, was the son of an Army officer and grew up in Army camps around the world. Somewhere in that experience, he developed into a very good and self-confident judge of people. There were people at MIT that he trusted implicitly, and there were others that he wouldn't trust any farther than he could see them. Sage trusted Gordon Brown, Stark Draper, of the Draper Laboratory, and I think I can claim that he trusted me. He had confidence in us, lent great support to us, and would do rather remarkable things for us. I remember when someone chartered an airplane to come back from somewhere because it was a sensible thing to do to get home for the weekend. That caused an explosion in the Military Contracting Office where they thought this was not an appropriate use of funds. The contracting officer went to Nat Sage as the senior person. Sage would listen to them, nod, sympathize with them and say, "That really is too bad." Then he would put the whole thing in his desk drawer. He would never even tell us that the question had been raised, because he believed it probably was a proper thing to do.

Gordon Brown, my mentor at MIT, and director of the Servomechanisms Laboratory under which the Computer Laboratory operated, was a person who threw a great deal of responsibility onto young staff members, even as research assistants in the Electrical Engineering Department. He provided an environment in which people developed very rapidly, and in which they could attach themselves to some important and overriding goal. To him, goes much of the credit for making the environment where the Whirlwind computer project could flourish.

In 1939, Perry Crawford did his MIT Muster's thesis on digital computation, which meant developing a ten-stage ring counter to compute with decimal numbers, but never carrying it beyond some individual computing circuits. He is a philosophical, looking-into-the-future type of person. By the time we made contact with him, he was in the Special Devices Center of the Navy in Port Washington, Long Island.

Perry Crawford is the person who first called my attention to the possibility of digital computation. We were standing on the front steps of 77 Massachusetts Avenue one afternoon when we were still working on analog computers in the Servomechanisms Lab. He began to tell me about the work on the Harvard Mark I computer, and about the ENIAC computer which was then under construction. He was a very uninhibited, unbureaucratic type and would circulate freely right up to the Naval Chief of Operations even though he was a civilian far, far down in the organization. He moved through the Navy selling the idea that digital computers had a future as Combat Information Centers. He had several computer projects under his direction that he raised money for. He is also the person who gave Whirlwind and other projects their names. All of them were named after air movements: Hurricane, Zephyr, Typhoon and Whirlwind.

The other promoter to whom we owe a great deal is George Valley, a professor of physics. He was on a committee of the Air Force looking into air defense. In the later stages of our work that led into Lincoln Laboratory, he was the person who would call up generals in the middle of the night, tell them what they should do, and ask for support. He did all those things you read exposes about in books on the politics of technology, but which are necessary to keep the program coordination running smoothly.

The Organization

Sometimes you have people in an organization, each of them with an IQ. of 130, and come out with an organization whose IQ, is 70. What you get is the least common denominator rather than the best of the participants. I'm not sure how one creates the opposite environment, but there is great power in a tightly knit organization that has the capability of using the strengths of each person and compensating for the weaknesses of each.

Every person has strengths and weaknesses. You need a team in which there are such things as a vision of the future, a sensitivity to political matters, the capability of developing people, technical competence, the courage to transcend adversity, salesmanship, integrity, and putting long-range goals ahead of the short term. We had those characteristics well represented, scattered throughout our group. No person had all of them. For every person there would be, perhaps, a glaring hole in one of those dimensions. Yet, it was a group that understood each other well enough to use people in situations where their strengths prevailed rather than their weaknesses. Out of that came an organization that was able to be much more effective than most of those we see around us in technology and in most corporations at the present time. It is still an unsolved challenge to understand how that sort of spirit and unity can be created.

The Hostile World

Another thing that helped us, but that we resented, was the hostility towards innovation. There was little outside understanding of our subject, the objectives, or the methods for building pioneering computers. Funds were almost always inadequate. Reviews and investigations required us to defend our position and to face the weaknesses that other people were pointing out. We benefited from the distractions caused by the periodic reviews in which everything was questioned. Why were we using so much money? Why were we running late? Why were we designing the machine the way we were?

The matter of cost was one of the things that the outside world understood least. Whirlwind was being judged in the context of mathematical research, in which the salary of a professor and a research assistant was the standard by which projects were measured. We were spending way beyond that level, and were seen as running a "gold-plated operation." Although the gold plating was occasionally excessive, in retrospect, I think there was reason for it.

An organization can't run with two contradictory standards. If you're going to have high performance and high quality in the things that matter, it is very difficult to have low quality and low performance in the things that, perhaps, don't matter. For example, at an early demonstration for important people, we didn't want them sticking their fingers into the high voltage in all those racks of Whirlwind. I asked somebody to get rope to put along the aisles so visitors wouldn't walk among the racks of vacuum tubes. A nice-looking white nylon rope was procured and installed. During the demonstration, I saw some of our critics fingering this beautiful rope and looking at one another knowingly as if to say, "That's what you would expect here." It may not have cost any more than hemp rope, but it reinforced that impression of an extravagant operation. Another example was the Cape Cod display scopes built into plywood cabinets faced with mahogany. Although our cabinetmaker made these quite inexpensively, people looking at those mahogany cabinets, were reinforced in thinking we were extravagant. Eventually we solved this problem by spending additional money and painting the cabinets gray.

From left to right: Jay Forrester, Norman H. Taylor, John A. O'Brien, Charles L. Corderman, and Norman H. Daggert ~ inspect the open, high voltage Arithmetic and Electrostatic Storage Racks characteristic of computer equipment in the early 1950s.
photo - The MITRE Corperation Archives

Whirlwind's Technology
Making the decision to build Whirlwind I with a 16 binary digit register length was tremendously hard for us. The mathematicians were up in arms. They thought it was too short to be of any possible use. We defended it at that time on the basis that it was a demonstration of feasibility and we would build a 32 or a 36 bit computer when the right time came. Many of today's desktop computers are still 16 bits and only now moving to 32 bits. Selecting 16 bits was not a useless register length for computing, only a serious short term political problem.

The objectives of a computer at that time dominated the kind of high-speed internal memory to be chosen. Since Whirlwind was for demonstrating a very high speed computation for real-time applications, we chose electrostatic storage tubes rather than any of the more reliable kinds of serial memories. Each electrostatic storage tube with 1024 binary digits cost us about $1000 and had a one month lifetime. That meant that the upkeep on a storage tube, just its replacement, cost about $1 per binary digit per month. If you were to spend that on your two-megabyte personal computer, it would cost you $24 million per year just to maintain computer storage. The improvement has been perhaps a million-fold since that time in cost. That's about a factor of two every two years in the intervening 40 years. The high cost of storage tubes was the major incentive for inventing and perfecting coincident-current, random access magnetic memory.

The economy necessary in programming was quite remarkable by today's standards. We demonstrated a military combat information center with one real bomber, one real fighter, and a radar set to generate data, with the computer receiving radar data by telephone line, analyzing it, throwing away the noise, averaging and smoothing and predicting the track, doing the same for the fighter, computing the intercept heading for the fighter, and then transmitting instructions to the autopilot automatically. If we today asked a programmer how much computer memory would be necessary for such a program, the programmer would probably guess a million bytes, minimum. The task was done on Whirlwind with 650 bytes of memory, not megabytes, just plain bytes. It was a time when the costs favored cutting programs to the minimum and using, if necessary, a lot of time, a lot of manpower, to reduce the programs.

Contributions of Whirlwind
In spite of the sense of extravagant expenditure, the entire Whirlwind project totaled about $4,500,000. That doesn't seem like much in today's computer world. Out of that came the first parallel, high-speed, clock-driven computer, magnetic core memory, cathode ray tube

displays driven by a computer, an interactive light gun connecting a person to the computer, and many other innovations that are still important today.

We thought we had a good view of the future and we did for the succeeding 15 years, but I must say that our view of the future did falter if you were to extend it beyond that time. I gave a talk in the mid- 1950s to a computer convention in which I pointed out that the cost of computation had been falling by a factor of two every two years from 1940 to 1956. I said, "Of course that can't go on for very much longer." But, of course it did, and is still going on.

The Whirlwind console room in 1951 with the marginal checking and toggle-switch test control panels on the left. Stephen Dodd, sitting at an input device, is being watched by Jay Forester and Hob Everett. Ramona Ferenz is seated at the prototype display to monitor the Cape Cod system, the prototype for SAGE.
photo - The MITRE Corperation Archives

Becoming a User
After 1956, I went more into the use of computers, using the ideas of feedback systems that Gordon Brown had originally pioneered and applying the methodologies and concepts to understanding the behavior of social systems. My present work is focused on the way in which the policies of a corporation produce its successes and failures and the way in which the policies embedded in the private and governmental sectors produce the behavior of the national economy.

My present work is focused on understanding the so-called economic long wave, the great rise and fall of economic activity with peaks every 45 to 60 years. This behavior has produced the great depressions of the 1830s, the 1890s, arid the 1930s. We believe that the present economic cross- currents are the beginnings of another such major downturn. Working on behavior of social and economic systems is now especially timely. Just as the frontier of physical science opened up in the 1800s, the frontier of understanding our social systems now lies immediately ahead.

The Whirlwind project had shown that a reliable real-time computer could be constructed and that aircraft could be tracked and intercepted. Robert Everett is shown here on the Control Force Demonstrator in 1947.

Discovering a "New World" of Computing

Robert R. Everett

Robert R. Everett is the former president of MITRE Corporation.

In 1947, the first work on how to use a general purpose digital computer for tracking aircraft was carried out at MIT. The project accounts for many firsts, because we were the first to ever have those problems. It was like Columbus and his crew discovering a new world. Jay was our Columbus and we discovered many strange and wonderful things. The computer business has grown to be like the original 13 colonies, with a vast, beckoning wilderness we have yet to explore.

The Whirlwind project proved that a realtime computer reliable enough to work could be built and that aircraft could be tracked and intercepted. But translating this experimental knowledge into an operational countrywide system was a major activity. Both technical and "organizational design" were needed.

The Birth of Lincoln Lab
The first step toward SAGE was the formation of Lincoln Laboratory by MIT, where we had a strong organization and excellent experimental verification and demonstrations. When the Air Force decided to go ahead with SAGE, Lincoln Lab was given the technical responsibility. An Air Force project office was set up in New York, supported by Western Electric. Bell Telephone Laboratories played a role in designing tests and criticizing what went on. IBM was chosen to build the central machine and Burroughs, to build some of the radar processors.

Lincoln was able to stay on top of SAGE because the group had done the planning backed by real experiments and demonstrations. Jake Jacobs created a systems office. Coordination meetings were held in which people from dozens of organizations, hundreds of people at a time, would get together. The group from Lincoln defined the problems, defined the options for solving those problems, and proposed decisions. We would present all this, and then everybody was faced with the option of either agreeing or taking some responsibility to do something else. They never wanted to do the work necessary for a new plan, so we always got our way.

The Role of IBM

The choice of IBM to build the central machine was made by Jay Forrester, with some help from Bob Wieser, Norm Taylor, and me. We visited the possible contractors and chose IBM because it was a very successful organization with strong sales and clean factories.

IBM had a series of machines in production and their own set of strongly held opinions about technology, standards, and organization. In the beginning we scud, "Thus is our business. We know what to do. You are here to manufacture it." They said, "We built computers long before you." We even argued about how to make the frames. They made frames out of square steel. We said, "You don't want to do that, it might rust on the inside and it won't last more than a few thousand years. You ought to use Lshape aluminum like we do." Over time, I think we came to understand each other.

We had to beam about communicating with IBM. Next to my office we put in a Teletype machine to communicate with Poughkeepsie. I arrived in the morning and just stared, fascinated, at this machine. I finally figured out why. I had always looked at Teletype machines or typewriters connected to computers that said dull things like "23" or "fault" or "redo." This machine said, "Good morning, it's a lovely morning in Poughkeepsie."

One lesson, I recall, involved working on the core memory. We built some 32 by 32 bit planes, and we knew we needed bigger ones than those but weren't sure we could handle the nonselect noise. Someone suggested we divide it up into quadrants and put a sense amplifier on each quadrant, which meant four sense amplifiers. Coming back from Poughkeepsie one night, I realized it only took two. I thought, "Wouldn't it be funny if we all died in a car accident and SAGE had four sense amplifiers?" The next morning, I rushed into work ready to tell everybody about the two sense amplifiers. On my desk was a memo from Bill Papian's s organization that said, "By the way, you only need two sense amplifiers." You had to be careful not to assume you were the only person who might think of something.

About 200 staff at Lincoln tried to stay on top of the project by turning the jobs over to other people as fast as possible. We didn't have the resources to do the design ourselves. Some of the troops at Lincoln didn't want to give up design because they felt strongly about what they were doing and weren't sure they trusted some "Johnny-come- lately" like IBM or Burroughs to build things properly. Fortunately, IBM wanted to take the job over as much, if not more, than we wanted to get rid of it.

It was a lot more difficult with the software. We had by then written the Cape Cod programs and had some feeling for the difficulty. We tried to get IBM interested in it and they said, "No, we sell equipment." So we tried AT&T who declined. Finally, Systems Development Corporation, spun off from the Rand Corporation, was created for this purpose.

The Air Force partnership The software turned out to take thousands of people. Jay set up a recruiting operation, and we hired hundreds of people off the street, unemployed mathematics teachers and so on. The Lincoln group hired hundreds of people for SDC.

Once the Air Force committed itself to building SAGE, they gave us complete support. For example, when we needed more computer time, we just bought it. The problem was that there weren't many computers around. Somebody had the bright idea that the machines in production in Kingston on the test floor were only being run two shifts. We needed time. IBM seemed willing. So we sent one of our fellows to IBM to negotiate it. He returned knowing it would cost a lot of money. Months later, Harris Fahnestock carne into my office, white and shaking, with a bill from IBM for a million dollars. I said, "Now don't get flustered, Harris. I know we should have told you, but you would've had to agree with it anyway so why don't you just pay the bill and go away?" And he did. You can't imagine that happening today. We probably all would have gone to jail. The Air Force never complained. They understood. They knew the computer time was needed. They knew it would cost money, and they paid the bill.

The way the Combat Center program was written involved getting Walter Attridge and busloads of SDC programmers to Syracuse, where the center was being put together. They wrote the Combat Center program at the site. Although it was a year late with a big overrun, it worked and worked well.

When the first SAGE center went operational on July 1, 1958, MIT's commitment was over. That fall, MIT spun off their Lincoln Lab

SAGE people to MITRE, which has been working on similar problems ever since.

About 20 centers were built. The ICBM put can end to the high priority that air defense has had, but the system ran for quite a while through the early 1980s. When the last centers went down a couple of years ago, they were still running well and reliably.

We had come to the end of the first part of the journey. I went to MITRE and Jay Forrester stayed at MIT. He was our Columbus, the first boss for many of us, the best boss for all of us, the creator of whirlwind and SAGE, Jay Forrester.

From World War II Radar Systems to SAGE

C. Robert Wieser

C. Robert Wieser is Director of Engineering at Science Applications International Corporation in Newport Beach, CA.

The 1949 detonation of a Soviet nuclear bomb was way ahead of the United States' time schedule for that event. Over night, the requirements for the air defense system changed drastically. The US air defense, patterned on the system used in the Battle of Britain, resulted in a five percent attrition rate for incoming bombers, i.e., 95% of the planes got through. With nuclear weapons, this rate was unacceptable. A chill went through the air of the defense community. Something had to be done. George Valley, Professor of Physics at MIT, understood that the existing system could not just be incrementally improved.

Improving the Radar System
Three major areas of the air defense system were identified that needed changing. The ground control intercept station that got information from a single, large, long-range radar, was dependent on the maintenance of a single station and only worked for aircraft targets at medium or high altitudes. H planes flew at low altitudes, long-range detection was impossible because radar follows line of sight, not the earth's curvature.

The second problem was that all of the processing of the radar data was manual. The detection of aircraft was done by men looking at oscilloscopes. Tracking was done by a grease pencil to mark successive radar blips on the scope. Vectoring instructions were done by approximation, the observer figuring out the right course to get to the right place and assigning a target time. Unreliable high- frequency radio was used to track radar from one station to the next. The time delays in the transmission spoiled matching up the tracks.

Finally, jet aircraft were just being introduced, aggravating the deficiencies of the system. Since the aircraft went much faster, it was harder for an operator to do intercept computations in his head and tell a fighter pilot where to find the target.

George Valley began to search for radically different new ideas needed to solve these problems. The first idea was to substitute commercial telephone lines for high-frequency radio. That was a social innovation because the military believed that its communication system should be completely independent of the communication system used by civilians regardless of their effectiveness.

George found that Jack Harrington, head of research at the Air Force Cambridge Research Center, was working on ways to reduce the bandwidth of radar data so that the radar picture could be transmitted over voice telephone lines. An experimental apparatus was working, hooked up to an old microwave early warning (MEW) radar at the Bedford Airport, now Hanscom Field. George understood that such a system would allow the integration of data from many radars into one network. Hooking radars together, a region the size of New England could be covered, and by including short-range radars that filled in the low altitude gaps, the coverage could be extended down to about 500 feet above the ground. These were powerful new ideas made possible by new technologies.

The next thing that George discovered was the existence of the Whirlwind project. Jay Forrester and Bob Everett told him about their earlier work foreshadowing automatic control. George saw the possibility of automating the radar surveillance data for whole regions of the country.

Real-time Control
At this time, I was working on the first program attempting to apply the digital computer to real-time car traffic control. My bright group of graduate students, called "Boy's Town," included Dave Israel, Bob Walquist, Jack Arnow, Howard Kirschner, and others. The group

was too inexperienced to be overawed by our task. overnight we converted from air traffic control to air defense.

The group followed an empirical, experimental approach, taking on the real world as fast as we could. Remote radar data carne into the Barta building where Whirlwind I was under contruction. At the time, Whirlwind had no electrostatic storage. Random access memory was five flip-flop registers and 32 toggle switch registers that could be read by the machine. We got the radar data inserted into the machine and displayed. After this happened we came face-to-face with some problems.

First, radars see a lot of things that aren't airplanes. That tends to load up the transmission system. Second, telephone lines were not perfected for data transmission. For example, dialing clicks came in as false targets. The progress in fixing those problems was very rapid because we didn't have to plead for permission. We just got the job done.

The next big event was when Whirlwind got one bank of electrostatic storage tubes with 256 registers. That was when we began to learn about the romance of computer programming. The word "software' had not been invented at the time. All of the programming was done in machine language because there wasn't anything else. With 256 registers, we extended the capability to simultaneously track- while-scanning ten airplanes. Alternatively, two airplanes could be tracked with vectoring instructions to indicate collision courses.

From left to right: C. R. Wieser, Bob Everett, and Jay Forrester gather at Forrester's retirement party in June, 1956.

Preparations began to try the real thing, an interception of two airplanes. We made friends with people in the Air National Guard and persuaded one pilot, who was flying a small twin-engine Beechcraft to be the target. Another pilot with a T-6, single piston pilot trainer, was asked to be the interceptor. To run the system, we had to communicate with the interceptor pilot and pass the computed instructions to him by voice telephone. That was Howard Kirschner's job. With no digital displays on the computer, Howard, with the wonderful wiring in his brain, could read the indicator lights off the registers, convert them to decimal, and send instructions to the pilot. In April, 1951, we ran the first successful interception. The T-6 carne within a thousand feet of the C-45. The impact of this accomplishment was so powerful that, three days later, the decision was made to build the Cape Cod System.

On January 16, 1956, the SAGE system of continental air defense was introduced to the press at Lincoln Laboratory. From left to right: Edward L. Cochrane, Vice President for Industrial and Governmental Relations; George E. Valley, Jr., Associate Director of Lincoln Lab; Major General Raymond Maude; Colonel D.E. Newton, Jr., Commander and Vice Commander, respectively, of Air Force Cambridge Research Center.

The Cape Cod System

This functional prototype of the air defense system was to be based on digital computation and remote transmission of radar data. Since it would be inappropriate to copy the hardware, Cape Cod was a functional prototype to test all the ideas for replication. Furthermore, it was a demonstration to ourselves, our friends, our skeptics, and our adversaries that this was more than intellectual nonsense.

The specifications for the Cape Cod System included doing air surveillance, automatically generating tracks, following the tracks, and generating vectoring instructions to interceptors. A group of Air Force enlisted men and officers were to carry out the project in two and a half years, from the spring of 1951 to the fall of 1953.

The system was completed on time with full functionality. Many engineering difficulties were encountered in building the pieces and putting them together because it was a new concept, made from new equipment, and new technology. Toward the end of the test period, the first core memory storage was installed on Whirlwind. The system went from 256 registers to several thousand, and the reliability was vastly improved.

In 1954, the system was expanded by increasing the radar network. The radars were located in Brunswick, Maine, Truro, Massachusetts, and Montauk Point, New York, and the interceptors included aircraft at Hanscom Field, bases on Long Island, and south of New York. Live exercises were run diverting Strategic Air Command bombers that were used as targets. Everything worked. A new development was the automatic ground-air data link so that Howard Kirschner did not have to read all those lights on the computer. It also foreshadowed the coming of missiles like the Bomarc which had no pilot.

The first ground-air data link experiments were interesting. Doc Draper of the Instrumentation Lab had a light test facility out at one end of Hanscom Field. Chip Collins, his chief pilot, discovered that one of the aircraft, a World War II B-26, Martin Marauder, had an autopilot that could take digital input. The radio frequencies were set up to send vectoring instructions directly to the autopilot. On the test we head Chip Collins say, "Let George do it," which meant switch to autopilot. A little while later, when we traced it on the scopes, he said, "Tallyho," as he sighted the target. Someone dubbed that "The Immaculate Interception."

With today's DOD guidlines, no such experiment could be carried out. In two and a half years, we wouldn't have been able to agree on an operational requirement, get an acquisition plan together, set up the RFP, the Source Evaluation Board, the Source Evaluation Advisory Council, the Source Evaluation Executive, and all the other groups, and still negotiate a DOD contract. At that time, we just did the job that was expected of us.

From Cape Cod to SAGE
The decision to build the SAGE System did not fall out of building and demonstrating the Cape Cod System. Competing schemes existed and there was a lot of missionary work to do to get our ideas accepted.

The burden of selling "electro-theology" fell on Jay Forrester and George Valley. Jay commissioned us to write Technical Note 20, a master plan for the development and installation of the "Lincoln Transition System." (The name "SAGE" had not yet been invented. George Valley brought in General Cordon Saville of the Air Force. He was about five and a half feet tall, feisty, had a strong voice and understood his own opinions. After he read TN 20, he came back, went to the head of the table, threw it down and said, "You're the worst damn salesmen I ever met. This report is stinko profundo. What you ought to do is start all over again, and maybe if you worked real hard, you might work your way up to medium sorry." We listened to him carefully and began to understand that it's one thing to explain something that lies outside a persons experience and yet another thing to explain something that lies outside his imagination. The latter is much harder, but it has to be done.

A Once-in-a-Life Experience
Sometimes I ask myself why this was such an interesting experience, the like of which I haven't had since. There are a couple of reasons. We were saved from the day-to-day frustrations of butting heads with the bureaucracy. We could invest all of our engineering skills in the task we had to do.

An important reason is that we had the engineer's dream: a nationally important problem that was interesting and difficult but not impossible to solve. These are the best kind. We were in a day-today contest with Mother Nature. The odds were bad, but we always had a chance to win, and we won all the battles that led up to SAGE. We also won the cause for digital computation. If there's anyone who thinks we didn't win, just go to Radio Shack and try to buy an analog computer.

Computer Space

Computer Space was the first coin-operated video game. It was developed by Nolan Bushnell in 1971. While "Computer Space" was a modest failure and only sold about 2,000 units, Bushnell's next game, "Pong,° was a tremendous hit that ushered in the era of video arcades and home game machines.

Produced while Bushnell was with Nutting Associates, the "Computer Space' flyer describes the game's "BEAUTIFUL SPACE-AGE CABINET" and "the reality of controlling your own rocket ship in gravity-free outer space." In fact, "Computer Space" was very near "Spacewar!" in terms of the action that it offered. The game's original instructions conclude with the offer, "If I can help answer any question concerning this machine, please do not hesitate to call me personally. Nolan K. Bushnell, Chief Engineer, Nutting Associates, Inc." The following year, 1972, Bushnell started a game company of his own -- Atari.

This photo is from the game's advertising and instruction brochure printed in 1971 It was donated to The Computer Museum by Alan Frisbie,

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