The ENIAC

by

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Introduction

World War II was a time of great technological advancement. Radar was invented to defend Great Britain from the bombers of the German Luftwaffe. Aviation was advanced by the jet engine. And no one will forget the climax of the war with the world's first glimpse of nuclear weapons over Hiroshima and Nagasaki. But none of these advancements were as significant to the twentieth century as the electronic digital computer. There are many stories about how the computer came into being, but the most exciting story is that of the ENIAC. It begins in 1938, the outbreak of World War II, and a large problem faced by the United States Army that was in dire need of a fast solution.

The Problem

As war erupted in Europe, the United States was recovering from the Great Depression and remained mostly isolated from the conflict. Society had turned inward, more concerned about domestic problems than international affairs. But as the war heated up, the possibility of U.S. involvement grew. The Army was unprepared for such a large scale conflict and began an effort to increase its firepower.

A large part of this effort took place at the Aberdeen Proving Ground (APG) in Maryland, where the Ordnance Department conducted its weapon testing. In order for the large guns that were being tested there to accurately reach their intended target, trajectory tables were produced which illustrated how far a shell could travel given the inclination of the gun. Many factors had to be taken into consideration when making these tables, including the angle of the gun, wind speed and direction, temperature, atmospheric pressure, humidity, and the types of guns and projectiles. To cover all of these conditions, many different tables had to be produced for each gun. Computing the trajectories for the tables required three-dimensional second-order differential equations of motion [LIFE]. The only computers that existed at the time were people, so all of the tables had to be calculated by hand, which took many hours. The Ballistic Research Laboratory (BRL) at Aberdeen was responsible for producing the tables, but was badly understaffed for the job. With the war accelerating, the demand for these tables increased. A method for speeding up the computations had to be found.

The Bush Differential Analyzer

In 1935, a mathematical computing device called the Bush Differential Analyzer had been installed at the Ballistic Research Laboratory to assist in solving scientific and engineering problems. It was a mechanical analogue machine invented in 1925 by Dr. Vannevar Bush of the Massachusetts Institute of Technology. A series of rotating shafts and wheels, powered by electric motors, ran problems through ten integration units to produce a solution.

The Ballistic Research Laboratory used the differential analyzer to help speed up the computations necessary for trajectory tables, but it had two major drawbacks. First, for each problem the machine was used to solve, many of its mechanical parts had to be refitted by hand, which was time consuming. The second, and more serious problem, was that an important part of the differential analyzer called a torque amplifier, which greatly improved the speed of the machine, failed frequently near the end of a long calculation. This failure resulted in costly down time as repairs were made.

In charge of the ballistic computation at Aberdeen was Lieutenant P. N. Gillon of the Ordnance Department. He knew that the Moore School of Electrical Engineering at the University of Pennsylvania had their own Bush differential analyzer, which was larger and faster than the one at the Ballistic Research Laboratory. In June of 1942, the Ordnance Department made a contract with the Moore School for exclusive use of the differential analyzer for producing trajectory tables. Put in charge of this contract at the University was Dean Harold Pender and Professor J. G. Brainard. Under these two was a large collection of talented scientists and engineers, including Assistant Professor Weygand, Dr. John W. Mauchly, and Dr. J. Presper Eckert. This team began working on new solutions to the Ordnance Department's computational problems.

The first improvements were modifications made to expedite the school's Bush differential analyzer. Professor Weygand replaced the unreliable torque amplifier with an electronic one. The input and output tables of the analyzer were also improved with electronics. These changes made the differential analyzer faster and less prone to failure, but it still wasn't enough for the Ordnance Department. Orders for new trajectory tables continued to arrive at an overwhelming rate.

Electronic Computing

One of the talents at the Moore School was Dr. John W. Mauchly. He had an idea. In 1941 he had made a visit to Dr. Vincent Atanasoff at Iowa State University. During this meeting, Atanasoff told Mauchly about his research into using electronics for numerical computation. Drawing from this experience, Mauchly got together with Dr. J. Presper Eckert to draft the design of an automatic electronic computer suitable for solving the differential equations for the Ordnance Department.

By this time Lieutenant Gillon had been promoted to Colonel. His new assistant, Lieutenant Herman H. Goldstine, was given supervision over the computational work at the University of Pennsylvania. Goldstine had received a doctorate in mathematics from the University of Chicago, making him well suited to the position. He and Professor Brainard presented Dr. Mauchly and Dr. Eckert's notes on the electronic computer.

On June 5, 1943, the Ordnance Department signed a new contract with the Moore School of Electrical Engineering to research, design, and build an electronic numerical integrator and computer -- ENIAC. It was to be supervised by Professor Brainard, with Dr. Eckert as chief engineer, and Dr. Mauchly as principal consultant.

The ENIAC

The machine designed by Drs. Eckert and Mauchly was a monstrosity. When it was finished, the ENIAC filled an entire room, weighed thirty tons, and consumed two hundred kilowatts of power. It generated so much heat that it had to be placed in one of the few rooms at the University with a forced air cooling system. Vacuum tubes, over 19,000 of them, were the principal elements in the computer's circuitry. It also had fifteen hundred relays and hundreds of thousands of resistors, capacitors, and inductors. All of this electronics were held in forty-two panels nine feet tall, two feet wide, and one foot thick. They were arranged in a "U" shape, with three panels on wheels so they could be moved around. An IBM card reader and card punch were used respectively for input and output.

The function of the machine was split into eight basic circuit components: the accumulator, initiator, master programmer, multiplier, divider/square-root, gate, buffer, and the function tables. The accumulator was the basic arithmetic unit of the ENIAC. It consisted of twenty registers, each ten digits wide, which performed addition, subtraction, and temporary storage. The accumulator can be compared to the registers in today's central processing units.

The initiator performed a few special tasks, including powering up and shutting down the ENIAC, clearing it, and starting computation.

The master programmer controlled execution of programs. While most of the programming was performed manually by setting switches and cable connections, the master programmer unit allowed for altering the program and iteration.

The multiplication and division/square-root circuits were used in conjunction with the accumulator's addition, subtraction, and storage capability to perform their respective operations.

The gate performed the logical binary "AND" operation (the output is positive if and only if all inputs are positive), and the buffer was used for logical "OR" (output is positive if any inputs are positive).

The function tables were used in the programming of the ENIAC. They were set with numbers and functions for the problem before hand, but could not be changed during program execution.

The ENIAC was programmed by wiring cable connections and setting three thousand switches on the function tables. This had to be done for every problem and made using the machine very tedious. However, the speed of the computation made up for this. Ballistic trajectories can take someone with a hand calculator twenty hours to compute. The Bush differential analyzer reduced this time down to fifteen minutes. The ENIAC could do it in thirty seconds.

Another drawback on the machine was a side effect of its reliance on vacuum tubes, which tended to burn out very often. This caused the machine to go through some ups and downs. It may have a few days of problems, but once they were all worked out it could run error free for weeks.

When errors did occur, they were found by stepping through the program one instruction at a time. The technical carried a hand held box with a button, which when pressed would signal ENIAC to carry out the next step in the computation. The results of each step could then be compared to the results of a computation carried out by hand.

Construction of the ENIAC was completed in the fall of 1945. On February 15, 1946, the Electronic Numerical Integrator and Computer was dedicated by the University of Pennsylvania. Its very first application was to solve atomic energy problems for the Manhattan Project. During its first year at the University of Pennsylvania, it computed ballistic trajectories for the Ordnance Department, as well as problems for weather prediction, cosmic ray studies in astronomy, random number studies, and designing wind tunnels.

In January of 1947 the ENIAC began shipment to Aberdeen, and by August of that year it was put into operation for trajectory tables. The technical staff at the Ballistic Research Laboratory had a difficult time with the large assembly of electronics, mostly due to the difficulty of programming it. But in 1948, by the advice of Dr. John von Neumann, alterations were made that turned it into a stored-program computer. This change greatly reduced the amount of manual re-wiring that had to be done for each program.

Other changes were made in the following years, including the addition of a high speed electronic shifter in 1952, which increased the speed of the computer by eighty percent. The following year a one-hundred word magnetic core central memory unit was installed by Burroughs Corporation. This latter enhancement gave ENIAC the ability to store larger amounts of information in a central bank of random access memory. Previously the only temporary storage was in the accumulator, which was very small and limited the types of problems ENIAC could solve.

Conclusion

The ENIAC was a revolutionary machine. During its development, the design had to be frozen to ensure that the working prototype could be completed in time for the Ordnance Department to get the trajectory tables finished. But the team who worked on it quickly found many areas in which it could be improved. These were later manifested in the successor to the ENIAC, the Electronic Discrete Variable Computer, or EDVAC. Other computers followed, including the Ordnance Variable Automatic Computer (ORDVAC), the Standards Automatic Computer (SEAC), and the UNIVAC -- the machine built by Dr. Eckert and Dr. Mauchly for the U.S. Census Borough when they left the Moore School to start their own business.

As computer technology advanced, the ENIAC itself became obsolete. During its time, it was the fastest computer in the world, but less expensive machines made it economically uncompetitive. At 11:45 PM on October 2, 1955 -- almost ten years after its dedication, the Electronic Numerical Integrator And Computer was shut down. Today, parts of the machine can be seen on display in various museums throughout the world, including the Smithsonian in Washington D.C., and in the very room where it was first constructed at the Moore School for Electrical Engineering of the University of Pennsylvania.

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