WHO INVENTED THE GENERAL-PURPOSE ELECTRONIC COMPUTER?

Arthur W. Burks

[This is a transcription of a talk given in Rackham Lecture Hall, The University of Michigan, on April 2, 1974. It has been edited somewhat.

Some slides were shown. These were made from photos and figures from my articles

[EI] "Super Electronic Computing Machines." *Electronic Industries* 5 (July, 1946) 62-67, 96.

[IRE] "Electronic Computing Circuits of the ENIAC." *Proceedings of the Institute of Radio Engineers* 35 (August, 1947) 756-767.

Copies of these articles are attached. The bracketed abbreviations will be used in referencing the photos and figures.

A ten minute 16 mm. silent movie film was also shown. The commentary has been removed from the lecture and an improved commentary attached as an appendix.

Judge Earl Larson's decision on the ENIAC trial (Honeywell, Inc. v. Sperry Rand Corporation, et al.) was published in *U. S. Patent Quarterly* *180* (March 25, 1974) 673-773.

The announcement of the talk follows. AWB]

COLLOQUIUM

University of Michigan
Department of Computer and Communication Sciences

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WHO INVENTED THE GENERAL-PURPOSE ELECTRONIC COMPUTER?

The 18,000 tube ENIAC (1943-1958) was the first general-purpose electronic computer. A 60 million dollar anti-trust suit on the ENIAC patent was recently completed in Minnesota.

Professor Burks, who was one of the principal designers of the ENIAC, was a consultant in the suit. He will show a 1946 film of the ENIAC, give a history of the machine, and relate it to the earlier Atanasoff-Berry special-purpose computer. He will then discuss the main issues of the anti-trust patent suit.

Part of the ENIAC is on exhibit in Frieze 2079, and you are welcome to see it any time. If the door is locked, ask a CCS secretary to unlock it for you.

Coffee and doughnuts 3:30-4:00, 2050 Frieze
Talk 4:00, 3532 Frieze

INTRODUCTION BY PROFESSOR BERNARD GALLER

It certainly is a pleasure to welcome you here, and to introduce to you Professor Arthur Burks of the CCS Department and the Department of Philosophy. I could say a great many things by way of introduction--I'll pick out just a few. Some of you know that Professor Burks was one of the founders of the CCS Department way back when it wasn't even a department, when it was an interdepartmental, intercollege degree program. Professor Burks was one of the people who called together a number of interested people who felt they had a number of things in common, although they came from as far away as Medical School, Engineering, LSA, etc.

He has always been very much involved in the history of computers and computer systems. I want to be sure to plug his course for this next fall, CCS 506, on the history of computers. More in connection with the Philosophy Department than with our Department, I understand there is a book coming out soon, *Cause, Chance, and Reason*, coming out from the University of Chicago Press.

The last thing I'll mention is the connection that Professor Burks had with the ENIAC, which is the stimulant for this lecture. The ENIAC was one of the very first computers and you'll hear enough about it shortly. Also, one of the very early important papers in computing was a paper on the design of the stored program computer, by Burks, von Neumann, and Goldstine.

We are very pleased to have the Burks of that paper with us, and I'm very pleased to introduce him to you. [Applause]

PROFESSOR BURKS

Thank you very much, Bernie, friends. The name ENIAC means "electronic numerical integrator and computer." I have two pieces here, this digit tray, which is part of the trunk system, and this plug-in unit. Later I'll show a short film of the ENIAC. We have an exhibit of about 10% of the ENIAC in the Frieze Building, which you're all welcome to see at any time.

The ENIAC was the first general-purpose electronic computer, and my main question is, "Who invented ENIAC?" This was one, but only one question, of a patent/anti-trust suit recently concluded in Minneapolis, between Honeywell and Sperry Rand.

The main question there was: "Should Honeywell pay Sperry Rand twenty-million dollars for infringing the ENIAC patent; or should Sperry Rand pay Honeywell sixty-million dollars for anti-trust damages, because Sperry Rand was trying to enforce the ENIAC patent?"

There are three important distinct stages in the development of the modern electronic digital computer. The first occurred at Iowa State University from 1937 to 1942. John Atanasoff, a Professor of Physics, and Clifford Berry, one of his graduate students, designed and built a special-purpose electronic digital computer. This was to solve simultaneous linear equations, and that's all it could do. It was low-speed, operating no faster than a relay machine.

That machine led to the ENIAC, which was constructed at the University of Pennsylvania during World War II, from 1943 to 1946. ENIAC was the first general-purpose computer. It was programmable; not easily programmable as we will see, nevertheless, programmable and general-purpose. It was high-speed; it worked at a thousand times the speed of Atanasoff's computer, or the Harvard Mark I, or the Bell Labs relay computers.

ENIAC was not a stored-program computer. It was not possible to store program information in high-speed read-write storage. Nevertheless, it led to the stored-program electronic computer, which is the third important stage in the development of the modern electronic digital computer.

The question, "Who invented the stored-program computer?" is a long and difficult question, at least as long and difficult as the question I'm trying to answer today. It has never been treated adequately. I plan to treat it in my course on the history of computers in the fall.

Of these three machines, Atanasoff, ENIAC, and stored-program, a patent was applied for only in the case of the second. That patent covered all electronic digital computers, including stored-program computers. But as you will see, the Atanasoff computer and stored-program computer development became involved in the Honeywell v. Sperry Rand suit.

Let me next give more details about Atanasoff's special-purpose computer. The storage was based on a drum system. [A crude model having two drums mounted on a shaft was exhibited.] Atanasoff took drums, placed metal knobs on the surface of the drum (for reading information in and out), and between each knob and the center shaft (which was metal) he placed a capacitor. He could charge that capacitor up to a certain voltage, say 50 volts, or he could leave it uncharged, 0 volts. The 50 volts was interpreted as a "one," the 0 volts as a "zero." He had 30 tracks. Each track had 50 knobs, so he could store thirty 50-digit numbers on each drum.

He built "add-subtract mechanisms," as he called them, which took the numbers from one drum and subtracted them from the numbers on the second. In that way he was able to solve 29 simultaneous linear equations by repeated subtraction.

This memory involves the principle of a revolver—it rotated one cycle per second. A capacitor, as you know, loses charge over time, so the memory also involves the principle of regeneration. Every time a capacitor came around, it was restored to its previous value. If the 50 volts had dropped down to 45 volts say, then the mechanism would automatically sense that and restore it to 50 volts. Atanasoff, using a human analogy, spoke of "jogging the memory." [Laughter]

Atanasoff used vacuum tubes for logical switching, not only in the arithmetic mechanisms that I've mentioned, but in the control as well.

Unfortunately, Atanasoff's machine was never completed. He stopped working on it in 1942 when he went off to Washington to do war research. He was still having problems, not with the electronic parts, mind you, but with the input-output. IBM would not give him a machine with which he could read into and out of his machine, because it was IBM's policy that nobody could connect into their machines. Similarly, it was AT&T's policy until recently that no one could connect into their lines.

He had an ingenious solution to this. He passed sparks through paper to make holes, and then he sensed the holes. But unfortunately the holes were not uniform enough that he could sense them reliably.

His trouble with input-output reminds me of ENIAC. It had 18,000 vacuum tubes. There was somewhat of a generation gap between the younger engineers at the University of Pennsylvania and the older engineers. Many of the older engineers said the ENIAC would never work. "A machine with 18,000 vacuum tubes! At any given moment at least one will not be operating. That one may be crucial to the answer, and you will get the wrong answer." Actually we, and Atanasoff, had more trouble with the input-output than we did with the internal electronics.

Now what were the novelties of Atanasoff's computer? First, it was electronic, using pulses; it was a discrete, binary system. Second, it employed a revolving, regenerative memory. And third, it used vacuum tubes for logical switching, both in the arithmetic unit and in the control.

I said before that the Atanasoff machine led to the ENIAC. This came about in the following way. John Mauchly was a physicist from near Philadelphia. He ended up, as did I, at the University of Pennsylvania during the war years (1941 to 1946). Before that, he went in June, 1941 to Iowa to visit Atanasoff and learn about his machine.

Even before John went, he had learned by correspondence from Atanasoff, of a more general idea. Atanasoff wrote to Mauchly that he had the idea of converting his machine into what he called an integraph. This is an important idea. How important it was one cannot judge, at least until one sees the evidence that Atanasoff presented in the recent trial.

The war that stopped Atanasoff gave rise to the ENIAC in the following way. The Ballistics Research Laboratory at Aberdeen Proving Ground had an important need to make firing tables fast. After a gun or shell has been designed, it's necessary to fire the shell through two magnetic loops to measure the resistance of the air to the shell. Not until you have that resistance function (a function of resistance versus velocity, which varies rather dramatically at the speed of sound) can you begin to compute the firing tables.

You then compute a firing table by imagining the gun at various angles, and for each of these angles, for a given amount of charge, compute the trajectory of the shell. Then having all that data, you rearrange it so that the gunner, who knows nothing about Newtonian mechanics or ballistics, is able to look in the table and say, for example, "If the target is seven miles off, I need altitude 27 degrees, 22 minutes, etc." The gunner must also take into account such things as the wind velocity and the altitude.

Firing tables were made before ENIAC in two ways. Most of them were done by computers, and here I mean women computers or human computers. They were mostly girls, because of the nature of the distribution of labor during the war. A clever girl, who was good at guessing, could integrate a trajectory step by step, by (say) a fourth order method, and do one trajectory in three days. Another somewhat faster method was to use the differential analyzer, what Atanasoff called the integraph. This was a mechanical analog machine. It could compute a trajectory in 30 minutes, but there were a limited number of these machines available for this purpose.

The object of the ENIAC, then, was to reduce the computation of a firing table from a matter of months to a matter of days. In June, 1943, we were given a contract by the Army to design, construct, and test the ENIAC. By the end of that summer we had reliable counters, reliable flip-flops, and reliable switches which could operate 1000 times as fast as the speed of Atanasoff's machine and 1000 times as fast as relays.

By the summer of 1944, we had two accumulators, two separate computers that could add back and forth between one another. By picking your parameters properly, you can integrate on two accumulators a simple differential equation that will produce a sine wave or an exponential. These two accumulators were tested in the summer of 1944.

We have at the CCS Department a very small simulation of that computation between two accumulators, which is in process of being developed. It will not operate at the original speed, but it will operate, and that should be available for your inspection soon.

Also by the end of the summer of 1944, about a year after we started, we had the general design of all of the machine and the specific design of a great deal of it. A year and a half after that, in December of 1945, ENIAC solved its first problem.

I'm sorry that I can't tell you what that problem was, because it's still classified. [Laughter] It was an H-bomb problem designed by Teller and Stan Ulam, one that could not be solved by means of the computational techniques and machinery available at the time other than ENIAC. It was solved on the ENIAC, successfully, if you count a negative solution as successful. That is, it was one of those many hypotheses that Edward Teller had as to how to make a hydrogen bomb that didn't pan out. It wasn't until many years later, around 1949, that Teller and Ulam together came up with a workable method of making an H-bomb.

This problem entered into the ENIAC trial because one of the issues that I'll mention later is "Was the machine used more than one year before the patent was applied for?" Both Edward Teller and Stan Ulam were witnesses in Minneapolis at the trial. Nobody had any idea of that at the time, of course. To us it proved that the ENIAC would work. It refuted the argument that a colossus with 18,000 vacuum tubes would not be reliable.

In February of 1946, three months later, we gave two demonstrations of the ENIAC, one for the press, another for military officers, scientists, and engineers. The internal workings of ENIAC were still classified, but we could show the machine and demonstrate what it did.

I was in charge of the demonstration: I explained what was to be done and pushed the button for it to be done. One of the first things I did was to add 5,000 numbers together. Seems a bit silly, but I told the press, "I am now going to add 5,000 numbers together" and pushed the button. The ENIAC added 5,000 numbers together in one second. The problem was finished before most of the reporters had looked up!

The main part of the demonstration was the trajectory. For this we chose a trajectory of a shell that took 30 seconds to go from the gun to its target. Remember that girls could compute this in three days, and the differential analyzer could do it in 30 minutes. The ENIAC calculated this 30-second trajectory in just 20 seconds, faster than the shell itself could fly! This convinced the military that electronic computers were feasible. [Laughter]

Let me talk next about the ENIAC patent. I have a copy here [he held up a copy]. You can buy it for 50¢ from the patent office. I won't tell you until the end how much it will cost you to build a computer that infringes the patent. [Laughter]

The ENIAC patent should have been filed in 1945. The basic design was done in 1944, though the machine wasn't fully tested until 1946. Nevertheless, it's prudent to file a patent as early as possible, and 1945 would have been the natural time. It wasn't done at that time, and this caused Sperry Rand endless trouble. I'd like to warn students about this, as it is a classical example of what can happen if you don't do your homework on time!

The patent was finally filed on June 28 of 1947. It consisted of a hundred project drawings, about a hundred pages of text, and at the end 148 long claims. Most of the text was taken from the reports that we wrote on the ENIAC. I wrote many of these reports and was the editor of most of them. John Mauchly and John Presper Eckert, who took out the patent, formed a business soon after. This later became the UNIVAC division of Sperry Rand, so the patent ended up in the hands of Sperry Rand.

The patent was delayed by proceedings in the patent office and the courts. There was an interference between IBM and Sperry Rand, IBM having certain patents or applications, and opposing the issuance of the ENIAC patent. This kind of proceeding can be held by the patent office, where the patent office operates as a kind of court, though the decision of the patent office is always appealable to the regular courts.

The interference with IBM was finally settled in 1956 as part of a settlement involving an anti-trust suit that Sperry Rand had brought against IBM. In this settlement IBM paid Sperry Rand 10 million dollars and cross-licensed its patents with Sperry Rand. IBM was given the right to use the ideas of the ENIAC patent if it ever issued.

There was an interference between Sperry Rand and Bell Labs, Bell Labs having certain computer patents. That was finally settled in 1962 after a trial in the New York District Court in which the judge decided that the demonstrations of February, 1946 were not cases of public use, and therefore did not invalidate the patent.

Finally the ENIAC patent issued in February 4, 1964, almost 17 years after it had been applied for. Remember, the life of a patent is 17 years! [Laughter]

Now it should be pointed out that delaying a patent may have tremendous economic value. If the ENIAC patent were valid, delay would have value in the following way. You can charge royalties for use of a patent for a period of 17 years starting from the date of issuance, not the date of application!

If the patent had been granted on the date of application, as proposed by some in current discussions of patent law, Sperry Rand would have drawn royalties on the computer business from 1947 to 1964. The patent being granted in 1964, that 17-year royalty period would take the computer business from 1964 to 1981. Assuming a 20% or 25% growth in the computer industry, you can imagine the large factor of amplification of royalty-subject output that's involved in a delay of 17 years.

This brings me to the issues in the Honeywell-Sperry Rand trial, which took place in Minneapolis, United States District Court, District of

Minnesota, Judge Earl Larson presiding. Actually the suit was filed in 1967, the trial started in about 1971, and ran about a year. Tentative judgment was issued about a year ago [April, 1973], and the final judgment was issued about last December [1973].

Now as you can imagine in a combined patent and anti-trust suit, with a patent as big as this [a copy of the patent was shown], the issues were tremendously complex. In fact, it started out as two patent suits. Interestingly enough, on the very same day, Honeywell filed a 60 million dollar anti-trust suit against Sperry Rand in Minneapolis, and Sperry Rand filed a 20 million patent infringement suit against Honey well in Washington. The trial in Washington came up first and the judge took one look at the patent and said, "Well, go out to Minnesota and try it at the same time as the other suit." They combined the two suits and they were tried in Minnesota.

I'll try to sort the issues out for you by putting them into three classes: issues of timing, anti-trust issues, and the issue of who the inventors were.

I'll start with the timing issues. A patent is a kind of monopoly since the holder of a valid patent has the right to charge anyone a royalty for using the idea covered by the patent. If a person doesn't pay that royalty, the holder of the patent can sue for the infringement of the patent and collect damages. Conversely, it's incumbent on the person applying for the patent to follow certain procedures and not to deliberately delay matters. This is the legal basis of the timing issues.

The first timing issue was a double one: prior "public use" and "on sale." The idea of public use is that once you get an invention and you pass it out to the public to use, you have only one year after that to apply for the patent. That's reasonable enough, because the patent shouldn't be delayed. The government's purpose in issuing a patent is to make the patented idea available so others will use it by paying royalties. Similarly with "on sale." If you sell an instance of the idea, or even offer it for sale, you have only one year to apply for the patent.

It's a real question as to whether the use of ENIAC in December 1945 to solve a classified problem was a public use. It certainly wasn't the general public. It was the government, and it was only a small part of the government, namely those people who understood what the problem was. [Laughter] It was difficult to tell the people from Los Alamos (Metropolis and Frankel) how to put their problem on the machine, when they couldn't tell us what the problem was. We had not yet worked out the manuals or procedures for programming ENIAC, but only had the information in our heads.

It's also a question as to whether the public demonstrations of February, 1946, again more than a year before the date of application for the patent, were public and 'on sale'. Obviously they were not in the ordinary sense. The public wasn't using it, though some of the public was watching it. The internal design was classified. The government wasn't offering to sell any machines, though it is true that after the demonstration Eckert and Mauchly, as the inventors, went to the Census Bureau and got a contract to develop a different machine. They developed this new machine, which was used in the 1950 census.

The second timing issue was that of prior publication. Were certain publications that appeared a year before the patent application prior publications in the sense of describing to the scientific community and the world how this machine worked? Some of the publications involved were my own publications.

Third, was there undue delay? It took 17 years to get the patent issued. Were Eckert and Mauchly originally, and Sperry Rand and their attorneys later on, responsible for unduly delaying this process? Let me remind you that there were interference suits from Bell Labs and IBM.

Fourth, were there any cases of late claiming? The patent applicant describes his device in a patent application, then at the end he claims what's novel in his device. There were 148 claims at the end of the ENIAC patent. The patent law allows you to change these claims before the patent is issued. This is reasonable, because if somebody else has a conflicting patent, you may be able to negotiate this, keeping some of your claims and dropping others. On the other hand, if you change claims unreasonably, that can invalidate a patent.

So those were the four timing issues: prior public use and "on sale," prior publication, undue delay, and late claiming.

The second class of issues concerned anti-trust matters. There were three of these. The first concerned misconduct in application at the patent office, either on the part of the applicants for the patents or their attorneys. The second concerned other alleged monopolistic practices, in particular, the 1956 IBM-Sperry Rand settlement I mentioned a moment ago. The third involved discriminatory licensing. Was Sperry Rand charging Honeywell too much more for the right to use this patent than Sperry Rand had charged

IBM?

The third class of issues contained only one, which is the main question of my talk: Who were the inventors of ENIAC? I'll read three of the many paragraphs of the complaint filed in Minneapolis by Honeywell.

Paragraph 10: The designation of Eckert and Mauchly as the joint and only alleged inventors of the subject matter shown and described in the ENIAC patent application, gave rise to a fatal legal defect, barring the subsequent issuance of any valid patent based thereon for the reasons hereinafter set forth. In short, to say that Eckert and Mauchly are the only inventors was incorrect, and was done incorrectly, and that invalidates the patent.

Paragraph 11, in part: The construction of the ENIAC machine was a complex team effort, requiring the joint and several contributions of a large group of scientists and engineers, working and cooperating together as co-employees of the University of Pennsylvania under government contract. Eckert and Mauchly by themselves initially contributed no more than an incomplete and generalized conception, which subsequently required the joint and essential effort of their many co-employees, including, among others, Thomas Kite Sharpless, Arthur W. Burks, Robert F. Shaw, and J. Chuan Chu. The exclusion of the naming of each of such others as co-contributors and joint applicants of the ENIAC patent application was willful, inequitable, and unlawful.

Paragraph 12: To the extent that the ENIAC patent application included claims to certain alleged broad inventive subject matter, such claims, and the contributions of Eckert and Mauchly defined thereby, were fully embodied in, and known by Mauchly to be, the prior inventive conceptions derived by him and embodied in the Atanasoff machine in Ames, Iowa. The inclusion of such broad claims in the ENIAC patent application and the withholding from the United States Patent Office then and thereafter of any admission of knowedge by Eckert and Mauchly of the Atanasoff machine was willful, inequitable, and unlawful.

Let me now explain my involvement in this, starting in 1964, after the patent was issued. Sharpless and Shaw had gone into the computer business in various ways and had many patents, some of which were handled by a man named Seymour Yuter, a New York patent attorney. After the ENIAC patent issued Yuter examined it—he knew a lot about the ENIAC because of related patents that he had dealt with—and he called Sharpless, Shaw, and me together to discuss the issue as to whether we might be inventors of the ENIAC.

He gave us the following criterion of "inventor," where a team effort is involved. He distinguished having a general idea from, as he called it, "completing the concept," working out the idea to the place where a design exists, which design can then be taken by anyone skilled in the art, and will eventuate in a construction. The question was: Had we formulated crucial problems and solved crucial problems? He pointed out also that it was wrong to think as we had thought, and as Eckert and Mauchly had thought, that the team leaders are the only inventors.

After considerable discussion and careful analysis of the 148 patent claims, Sharpless, Shaw, I and Yuter concluded that we three were inventors. Paragraph 11, which I read, reflects that conclusion. That is, Honeywell was really adopting our theory when they put forward that paragraph of the complaint.

I'd like to emphasize at this point, in fairness to Eckert and Mauchly, both of whom are long standing friends of mine, that there were many Honeywell charges, some of which we accepted and some which we did not. The principle that Eckert and Mauchly were not the only inventors, but Shaw, Sharpless, and myself were also, was the principle that we accepted, and indeed put forward.

The principle also enunciated in that same paragraph, that Eckert and Mauchly omitted our names willfully and deliberately, didn't seem to us correct at all. At the time Eckert and Mauchly thought that they were the inventors and indeed we had agreed. Also, in our minds, Eckert and Mauchly were still the main inventors. The only question in our mind was, "Were we also inventors?" and we decided we were. I should like further to emphasize that we felt that others of the ENIAC team had made important contributions, but applying the criteria that we had, it did not seem to us that they were inventors.

Next I'd like to give you more details on the ENIAC so that you can see how it differed from Atanasoff's machine, and get an idea in your own mind as to whether you think the ENIAC represented an invention. There's one principle I'd like to invoke, which I'll express with a story. The principle is that sometimes after the fact things look much more obvious than they are before the fact.

The story concerns Sir John Fleming, who invented what he called a thermionic valve. That was an electronic diode, or a tube that had a cathode and a plate in a vacuum. It would allow electrons to flow from the cathode to the plate but not in the reverse direction, so it served as a rectifier. This was an important invention, made by Fleming in 1904. It allowed you to replace the crystal of a crystal radio set by a diode, and it allowed you to convert alternating current into direct current.

Three years later the American Lee De Forest patented what he called an "audion." That was a triode, an evacuated tube with three electrical elements: a cathode that emitted electrons a plate that collected electrons; and in between a grid of wire, which could control the flow of electrons from cathode to plate. That was important, because with a small amount of energy on the grid, one could control a large amount of energy through the tube.

De Forest's invention made many further inventions possible: audio amplifiers, radar, hi-fi, and electronic computers. The ENIAC had 18,000 tubes of which roughly two-thirds were triodes. None were diodes, for there was no advantage in using a diode over a triode. Some tubes in ENIAC were more complicated than the triode, having several grids.

Now the point of my story is this. Fleming and De Forest got involved in patent litigation over whether De Forest had invented anything. Looking back, it seems obvious to us that Fleming had invented something, the diode; that was an important thing. Then De Forest had definitely improved it by putting in the third element, and that was another invention.

Sir John Fleming did not think so. [Laughter] His comment about De Forest's triode was "All De Forest ever did was put another wire in my tube." [Laughter]

Now let me show you a little of the ENIAC in reality and in picture. [Stepper plug-in unit displayed.] Wherever possible we put the vacuum tubes and circuits on units like this that could be removed. We called them "plug-in units." So if the maintenance man suspected trouble in one of these units, he could pull it out, put in a unit that he knew worked properly, and then take this unit to a work bench and put it in working order. This helped him isolate errors. This particular plug-in unit is from the master programmer.

I mentioned programming the ENIAC. Subroutines were set up, as I'll show you in the film, by making plug connections from one unit to another, and by setting switches. Program pulses ran around the machine through a trunk like that [pointing to the tray he had in front], and activated the different units of the machine. [The eight foot long program trays can be seen at the bottom of the pictures on p. 62 and p. 63 of EI.]

The ENIAC was, to use modern terminology, a multiprocessor. It had 25 different calculating units, all of which could operate simultaneously, communicating with one another through trunks made up of units like this program tray.

This unit of the master programmer [pointing to plug-in unit] was basically a counter of six stages with some associated circuitry, which we called the "stepper." Its function was to merge several subroutines that were set up by means of cables and switches into a single program. It could operate one subroutine for a while, maybe for 79 operations, another subroutine for a while, maybe for 50 operations, and then another one for a while, until a number changed sign (there was a conditional instruction in the machine), and so forth.

What we have down here is only one of many trays. It consists basically of 11 shielded wires. The ENIAC was a decimal machine, and we transmitted in parallel all 10 digits and sign of the decimal number, so that an addition could take place in 200 microseconds. In other words, ENIAC could perform 5,000 additions per second. These trays went around the front of the machine and constituted many different trunks.

When I asked one of our CCS students to help me carry this [eight foot metal tray] up from downstairs, he was very obliging, but he looked as if it was kind of junky and asked "What's that!" So I said: "That's a communication channel of ENIAC." He continued to look puzzled, so I added: "ENIAC was the first general-purpose electronic computer." He still looked unimpressed. Finally I said: "That's part of the trunk system of ENIAC, the first *multiprocessor*." Then his face lighted up, and he rushed to help me! [Laughter]

Yet ENIAC was not really a multiprocessor in the modern sense. ENIAC could do many things simultaneously: multiply, divide, look up stored function values, add, and subtract. It could run several problems in parallel. But no unit of ENIAC could compute by itself, just as no unit of the differential analyzer could compute by itself. And, of course, it had to be slowly and clumsily programmed to do these things.

The ENIAC was a large machine, as you'll see in the first slide: 18,000 vacuum tubes, 80 feet long. [EI, p. 62. See also Fig. 1.] It was arranged in a U. Each of those little blocks is a separate unit, two feet wide and about eight feet high. We have four such units in our static display in the office next to mine: two accumulators, a third of the high-speed multiplier, and half of the master programmer.

It was a mammoth machine. Judge Larson in his decision refers to it once as a "monstrous machine." But I'd like to emphasize that it was the first general-purpose computer, and it did work, and it solved problems that were not previously solvable because of its general-purpose character and its speed.

By going around this picture I can indicate the units: an initiating unit, where you started things; a cycling unit, which produced a set of basic synchronous signals, so that all of the units could operate in synchronism; a master programmer, which controlled all of the subroutines to make them into a viable routine, or more than one routine. One could have several problems on the machine at the same time. For the demonstration we had part of the Los Alamos problem, various small problems, and then a trajectory.

There were twenty accumulators, spaced at different places. Each could store a number and could add or subtract. All of these units, mind you, had their own programming facilities.

Then comes a divider-square-rooter, which divided by repeated subtraction and square-rooted by repeated subtraction (the algorithms are very similar). Here is the high-speed multiplier, on which I worked a lot. It consisted of three panels, and had the capability of multiplying one decimal digit of the multiplier by the whole multiplicand in a single addition time using a multiplication table that we'll see later. A ten-digit multiplication could be performed in 13 addition times, or roughly 400 per second.

There were also facilities for double precision.

There were three function tables with their matrices. The function table matrix and the multiplication table matrix were made of resistors and were read-only memories. Remember that all high-speed read-write memory in the ENIAC consisted of vacuum tubes. There was not at that time any cheaper or smaller high-speed read-write memory. There was cheaper read-only high-speed memory, which involved using resistor matrices so as to get a rectifier action. When ENIAC was used for firing tables the girls would set switches on these function table matrices. [The corporal in the left foreground and the young lady in the right rear of EI 62 are setting switches on function table matrices.]

For input there was the constant transmitter which received information from an IBM card reader. For output there was a printer which received numbers from the accumulators and sent them to an IBM card punch. The input and output were slow, being governed by relay speeds.

The next slide shows the different pulses that were produced by the cycling unit, which was a complicated central clock. [EI Fig. 8, IRE Fig. 6] The philosophy here was never to create pulses from pulses, but only to control and re-route pulses that came from the cycling unit. This was to prevent successive degeneration and to help guarantee reliability. There are many other principles that were employed to guarantee reliability that I don't have time to mention.

The basic addition time was 20 pulse units long. Each pulse lasted about 2 or 3 microseconds. They were spaced ten microseconds apart, giving a fundamental rate of 100,000 pulses per second. Ten pulse times were needed for the addition proper. The other ten pulse times were needed for carry-over and for setting up the program controls so that the units would be ready to operate.

At the time of the demonstration the news media came down and took films. In those days there were theaters that showed newsreels as their whole fare. The camera men shot some films of the ENIAC, most of which were burned in an accidental fire later on. These films were not shown much at the time, because other more important news preempted ENIAC. I have here about ten minutes of the original newsreel. [See the appendix for a commentary on this film.]

Now we can go back to the slides. I want to give you a rough idea of the complexity of the circuits.

[IRE Fig. 2] Here is the block diagram of a decade, which could store one decimal digit, could receive a digit in pulse form and add it to its contents, with carry-over, and could transmit both its contents and the complement of its contents. Each of those little squares is roughly a vacuum tube.

[IRE Fig. 1] There's the circuit of the decade ring counter. See the circles? There you see De Forest's triode, with a black line at the top for the plate, dotted line for the grid, and a bent-over line at the bottom for the cathode.

[IRE Fig. 5] Binary ring counter: this is a two-stage counter used for storing the sign of a number.

[IRE, upper half of Fig. 4] There's a multiplication table circuit. Those little wiggles along the diagonal are resistors. One line on the left, 0 through 9, would be stimulated, and that would produce a bunch of products. For example, if you stimulated line 6, you would get from the bottom the products of 6 times each of the digits 0 through 9, each digit of the products being represented by a pulse stream.

[IRE Fig. 7] This shows a cross section of the multiplication table circuit.

[IRE Fig. 4, lower half] This shows how the multiplier selected the proper digits. The diagonals down below are for shifting the partial products.

[EI Fig. 7] Here's a simplified version of an accumulator program control circuit. It appeared in a published paper of mine in 1946. This paper antedated the patent by more than one year, but did not show enough details of ENIAC to invalidate the patent.

This is the end of the slides.

ENIAC was general-purpose, i.e., programmable. It had subroutines and a master programmer, but the program could not be stored electronically so as to be read electronically. It was a high-speed electronic machine that could solve many problems that were not previously solvable.

I'll conclude this talk by summarizing the decision of Judge Larson, what he called "findings of fact, conclusions of law, and orders of judgment." Remember, there are three classes of issues: timing, anti-trust, and "who were the inventors?"

Judge Larson found in favor of Honeywell on three of the four timing issues. He ruled that there was prior public use and that the ENIAC was on sale more than one year before the patent was applied for. He ruled that there was a prior publication. This was not my article, from which the last slide came, but a draft report by von Neumann on the first stored program computer. This report was very important, and had been circulated in a very limited way, but it had never been intended by von Neumann for publication at all. On the third timing issue the judge found in favor of Sperry Rand. He ruled that there was no undue delay on the part of the applicant, though he concluded that "with reservation." But on the fourth issue, late claiming, he found for Honeywell. A definition of "pulse" had been inserted in 1963 which widened the scope of the claims. That was illegitimate.

On the second class of issues, the anti-trust issues, the judge found in favor of Sperry Rand. But he nevertheless had harsh words to say. I read from a published summary: "The court discovers a wide variety of practices by the patentee," [now that would be any of Eckert, Mauchly, their lawyers, and Sperry Rand lawyers] "that it considers unsavory [laughter], yet stops short of finding fraud, but it does rule the patent unenforceable, however, on the basis of the patentee's numerous derelictions."

The second anti-trust issue concerned monopolistic practices. The judge stated, and I'm quoting now from *Datamation*, "that the IBM-Sperry Rand agreement of 1956 damaged Honeywell to the tune of between nearly 400 million to nearly 575 million, during the years from 1958 to 1967. However, Honeywell may never be able to collect damages because of a four year statute of limitations." [Laughter]

The third anti-trust issue was that of discriminatory licensing. You remember that Sperry Rand was asking Honeywell for a 20 million license fee. Earlier, according to the papers, Sperry Rand even talked about 250 million dollars for the right to use this patent! IBM and Sperry Rand had settled in 1956, though that was of course before the patent issued, and one didn't know for sure that it was valid. Indeed IBM thought that it was probably not valid because of public use. IBM and Sperry Rand had settled for 10 million. While the judge ruled there was not really discriminatory licensing, he said "It's strange logic to ask 20 million of a small company when you settled for 10 million for the colossus that monopolizes the industry."

This brings me back to my main question: Who were the inventors of ENIAC? And here I will quote from the decision.

Paragraph 3.1: The subject matter of one or more claims of the ENIAC was derived from Atanasoff, and the invention claimed in the ENIAC was derived from Atanasoff.

3.1.2: Eckert and Mauchly did not themselves first invent the automatic electronic digital computer, but instead derived that subject matter from Atanasoff.

3.1.3, in part: ENIAC is not patentable over subject matter derived from Atanasoff. [For example, claims 88 and 89 were derived from Atanasoff.]

4.2.1: Arthur Burks made major contributions to the design of the accumulator and the multiplier of the ENIAC, and signed at least 77 drawings. [Laughter]

He also mentions Sharpless and Shaw, and he furthermore mentions Davis, Mural, Chu, and Sam Williams of Bell Labs as making important contributions.

So in brief, Judge Larson held that ENIAC was a joint team effort involving others besides Eckert and Mauchly. He also held that ENIAC was not an invention because it derived from Atanasoff. Thank you. [Extended applause.]

DISCUSSION

Galler: The only "word" that comes to mind for a talk like that, is "beautiful." Professor Burks said he would answer questions, but people should feel free to leave if they wish.

Are there any questions? I guess I have one; let me take advantage of my position to ask it. [Laughter] My question is: Were you and the others aware of the Atanasoff relationship, the transfer of information from Atanasoff to Mauchly?

Answer: Yes and no. John Mauchly never made any attempt to hide how he conceived his relation to Atanasoff. That is, he never hesitated to talk about his visit to Atanasoff in June of 1941. John used to talk about the machine.

But I never saw his correspondence with Atanasoff. It came as a surprise to me when, during the process of the suit before the actual trial took place, I learned of the letter in which Atanasoff had proposed generalizing his special-purpose machine to what he called an integraph. As I mentioned earlier, that is important; how important it is would depend partly on exactly what Atanasoff said, and I have not seen what Atanasoff said in court. It's not easy to get these materials, and they're not cheap. The court usually charges 50¢ or $1.00 a page for a transcript.

On the other hand, there is such a thing as a digital differential analyzer, which is very different from the ENIAC. Also, if you accept the philosophy that it's not enough to have an idea, it's necessary to complete the conception, that also is important.

* * *

Question: To what extent did the idea of the machine propagate through later machines? What was the importance of the ENIAC in that respect?

Answer: Well, it showed that a large computing system would work. It showed that you could count rapidly and reliably. There were counters that counted rapidly before; physicists used them for cosmic rays. But in experimental work you don't care if you drop a pulse or two, so they wouldn't have done for our purposes.

What was needed to make a good general-purpose computer was cheap storage. A vacuum tube of the size here [shows a tube]—it's actually two triodes in one bottle—is a pretty large and expensive device. Out of the ENIAC, out of this revolver regneration idea, and out of the use of mercury machine of that power, is a considerable achievement.

* * *

Question: What was the cost?

Answer: The original extimated cost was 80 thousand dollars or so, but they kept changing the specs as to what they wanted, a familiar process nowadays. The actual cost of the machine to completion was something like 300 thousand dollars, maybe 400, and it cost them an awful lot of money to move it. I thought it was silly to move it. The machine then operated at Aberdeen from 1947 to 1956.

* * *

Question: As a result of all this, if we were to build another ENIAC today, what would one's patent liability be?

Answer: Well, you see the judge decided that this patent is invalid, that Eckert and Mauchly are not the inventors, that it's invalid for reasons of timing, such as public use, on sale, and prior publication. It's not invalid for reasons of anti-trust.

This decision could be appealed. Indeed, at the end of the judge's findings of fact, conclusions of law, and summary of judgment, he puts in all kinds of provisos as to what should be done if he's overruled on these points. He might be overruled, you see, on deciding that Eckert and Mauchly were not the inventors. He might be overruled, and some higher court say that anti-trust damages were in order.

The actual fact is that the suit was settled by Sperry Rand and Honeywell, with Sperry Rand paying Honeywell about 3 million dollars. Now, I'd like to point out that running any trial is expensive. Running an anti-trust trial, where you must get a terrific amount of data, is very expensive, so it would be my guess that the basic settlement was that Sperry Rand contributed an appreciable part, but not the total, of Honeywell's expenses.

* * *

Question: Does that mean as a result of this that anyone can go out and build a machine and not worry about this patent?

Answer: That's right. That's what it means. I should point out that there is generally in the computer industry now a free exchange of patents. Generally the big companies do not try to enforce their patents. Individuals or small companies will. But Sperry Rand felt that because the ENIAC was unique it should be excepted from this, and they actually set up a special corporation, ISD, in Chicago to enforce the patent.

* * *

Question: What would it cost now to build a machine of that capacity?
Answer: There are different ways of putting it. Let me put it in terms of size. With large-scale integrated circuits you can, with present technology, make a machine as powerful as ENIAC, excluding input-output, this large. [He held up his hand.] And in 10 years you'll be able to make it as complicated and put it on the end of your thumb.

A little computer you can buy for $3500 would be more powerful. The latest computers that you get from Hewlett-Packard for less than a thousand are not as powerful. But remember ENIAC was made a long time ago.

* * *

Question: How does von Neumann fit into the ENIAC?
Answer: In the part that I'm telling, he doesn't enter in a contributory way at all. To give you the dates: we started in 1943, we had two accumulators working the summer of 1944, and he came in about August of 1944 on his first visit. He served as a consultant and came back periodically.

Later, after the ENIAC was moved to Aberdeen, he and some other people, including a man named Clippinger, conceived of a way of centrally programming it on those function tables, by setting switches. So he made that later contribution. He fits in with respect to the stored-program computer, but I don't tell you that story unless you take my course. [Laughter]

* * *

Question: I've heard stories that imply that the way you described it doesn't fit what actually went on, but that, basically, whoever initially let out the contract didn't know what they were getting into. Where did the intent come from that started with a project to build something to calculate firing tables and ended up with a general-purpose computer?
Answer: I don't think in that sense your story is true. It came about this way. The Moore School of Electrical Engineering, which is the elec. cal engineering part of the University of Pennsylvania, where all this happened, had very close ties to Aberdeen. It had built a differential analyzer for Aberdeen. There was constant consultation. And when Aberdeen had more girl computers than they could handle, in the sense of having space and housing for them, they contracted with the University of Penns

vania to take these girls, train them when they needed training, though many didn't need training, find more such and train them, and provide the computing facilities needed. To supervise this activity they sent up a civilian and a military man. The military man was Herman Goldstine.

He was a mathematician. The Moore School was a small school, with a faculty of about a dozen and a hundred undergraduate students, so naturally we met and started to talk, and before long, John Mauchly was telling Herman that the best way to do trajectories was electronically. And Herman said "fine," tell me how to do it. John said, "Well, I wrote a memorandum proposing this, and gave it to Grist Brainard." They went to Brainard who couldn't find it.

Then Eckert and Mauchly drew up a proposal in April of 1943, and went down to Aberdeen with this proposal along with Brainard and Goldstine. A famous mathematician from the Institute, Oswald Veblen, was a consulting mathematician there. They met before the committee.

If you read Herman Goldstine's book, *The Computer from Pascal to von Neumann*, he tells all of these stories in detail. One of the engineers, a man named Johnson, who happens to be an uncle of my brother-in-law, had some doubts as to whether this large machine would work. These doubts were discussed, and then at one stage Oswald Veblen sat back in his chair and said, "Simon," (the colonel in charge was Colonel Simon) "give him the money." So they got the money. [Laughter]

Now you want to remember a couple things here. That $80,000, which was the original figure, looks like small potatoes for development now. Almost any professor can get 80,000 for a research grant. But at that time no industry would have conceived of putting 80,000 dollars into such a scare-brained project as this. It was only because of the war and the need of the war that the government was willing to put that money up.

* * *

Galler: Thank you very much. [Applause]

Commentary on ENIAC Film

Arthur W. Burks

At about the time of the ENIAC dedication (February, 1946) two newsreel companies made silent 16 mm. film shots. These were to be edited and then shown as newsreels in regular theaters and also in theaters that specialized in newsreels and short films. I produced a written commentary, and also went to New York City and advised the editors.

These films were not shown much at the time, being pre-empted by news regarded as more important. The most important news at the time was the appointment of some new cardinals by the pope of the Roman Catholic Church.

I have heard that most of the film taken of the ENIAC was later lost in a fire. I have obtained two short reels of unedited and hence disjointed scenes, of which this is the best. It is about ten minutes long.

I'll make a few remarks about the ENIAC and the people in the film and then give a shot by shot commentary.

The ENIAC was the first general-purpose electronic computer. It consisted of 30 semiautonomous units of four basic kinds.

(I) Computing units

- 20 accumulators
- high-speed multiplier
- divider square-rooter
- 3 function tables, each with a portable function table matrix

(II) Input-output units

- constant transmitter (with IBM card reader)
- printer (with IBM card punch)

(III) Central program control units

master programmer

initiating unit (in part—this unit consisted mostly of test circuits)

(IV) Central timing unit: cycling unit

Each unit occupied one, two, or three racks, 2 feet wide and 8 feet high.

Each computing and input-output unit had two kinds of circuits: numerical and control. The units communicated with each other through the trunk systems: one for numbers (digits) and one for control (program) pulses. Correspondingly, an ENIAC program had two parts: a numerical part and a control part. For each part the programmer set switches on the panels of the units and also made cable connections between those panels and the appropriate trunk system. The numerical trunk system was above the control panels and the program trunk system was below.

ENIAC was designed by a team of engineers, of which Pres Eckert and John Mauchly were the leaders. Of the other engineers, you will see Kite Sharpless and me. Herman Goldstine persuaded the Ordnance Department to finance the project. Homer Spence was an Army maintenance person and operator. You will see several young women programmers and operators, including Kay McNulty (now Mrs. Mauchly), Francis Bilas (now Mrs. Spence), and Betty Jennings.

COMMENTARY ON THE FILM

Eckert and Mauchly in front of the initiating unit and cycling unit

Pres Eckert is on the left and John Mauchly on the right. Kay McNu[illegible] brings them a paper.

Burks and Goldstine in front of high-speed multiplier

I'm on the left and Herman Goldstine is on the right, in front of [illegible] three racks of the high-speed multiplier. From the top down you see wiring, the digit trunk, the control panels, and the program trunk.

People programming ENIAC

Several people are doing both numerical programming and control programming on the computing units. To program one plugged in cables and set switches. In the foreground Betty Jennings is programming the master programmer, which combined the subroutines set up on the local units into a single master routine.

IBM punched card machine

We used IBM machines for input and output.

Spence replacing a plug-in unit

You'll see the rest of this scene later.

IBM punched card machines

The operators placed input data in the card reader and removed the output from the card punch.

Spence replacing plug-in unit (continued)

Spence has removed a defective plug-in unit. He replaces it with one known to work correctly.

Desk calculator vs. abacus

Francis Bilas is operating a desk calculator in feigned competition with Kite Sharpless, who is using an abacus. Desk calculators like this were used by the young women to compute trajectories.

In 1946 few people were acquainted with IBM machines or desk calculators.

People programming ENIAC (again)

They are plugging cables and setting switches according to written instructions. After the program was worked out on paper, it took a couple of days to set up the machine.

Setting switches on a portable function table matrix

The numbers were entered by hand. The machine read them electronically.

IBM punched card machines (again)

In a moment you will see a wired plugboard at the lower right. It contains the program for the IBM machine. This was the source of the method of programming used in ENIAC.

Test equipment on initiating unit

A problem was started at the initiating unit. But most of the equipment on this unit was for testing. These meters are for reading any of the approximately 70 direct current voltages.

High-speed multiplier (again)

The diagonal lines are the outputs of the shifter circuits. For each successive digit of the multiplier the partial products were shifted one more position to the left.

View of programming cables and switches

Portable function table matrix (again)

Display panel for this film

Here are some display lights which are operated by the vacuum tubes below. The display panel was made for this film since little neon lights on the machine itself were not bright enough to be photographed.

All counters had small neon bulbs to show their state, and the same was true of flip-flops. This display board shows how an accumulator's lights might look during addition or subtraction.

When ENIAC computed a trajectory one could see the abscissa value gradually increase as the shell traveled out, and the ordinate value go up and then come back down as the shell rose and then fell.

In the public demonstration of ENIAC we computed the trajectory of a shell that took 30 seconds to reach its target. A young woman with a mechanical desk calculator spent two or three days calculating such a trajectory.

ENIAC computed the trajectory in only 20 seconds, faster than the shell itself traveled. This convinced the colonels and generals present that electronic computers were important.

Portable function table matrix (again)

Goldstine is reading numbers and Spence is setting them on switches.

This is where the resistance table for a shell was stored. That table gave the resistance of the air to the shell as a function of the shell's velocity.

Display panel (again)

These lights seemed important to the film crew. They felt the public could understand visual communication between man and machine better than communication by punched cards.

Eckert and Mauchly (again)

Here's another shot of the scene we started with. Pres is on the left and John on the right.

They planned ENIAC and directed the development and construction of it. After the war they formed a company, which eventually became the UNIVAC division of Sperry-Rand.

7/20/77

This film lasts about ten minutes.