# Computers at the University of Pennsylvania's Moore School 1943-1946

## The Jayne Lecture

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A description of my own experience may perhaps serve to introduce the ENIAC project. I obtained my Ph.D. at the University of Chicago in 1936 and then for a number of years was a research assistant in the mathematics department there, teaching among other things a course in exterior ballistics. Thus, when I was called into the service, I was assigned to the Aberdeen Proving Grounds Ballistic Research Laboratory. On 7 August 1942 I reported for duty. I was then a first lieutenant and was assigned at once to Paul Gillon, a regular Army officer who had charge of all ballistic computations.

On September 1 Gillon and I went to inspect the small activity the Laboratory had at the University of Pennsylvania's Moore School of Electrical Engineering. We found things there in a not very good state. I was placed in charge of the entire operation in Philadelphia and proceeded to make it operational.

Dean Pender of the Moore School had assigned the task of liaison with Ordnance to John Grist Brainerd, who was then a professor in the Moore School and who was later to be Director. Brainerd was perhaps the best qualified member of the faculty for this purpose. He combined a considerable interest in computation with substantial ability as a leader of men and a manager of affairs. He did an excellent job of handling this assignment, which was soon to occupy him full time. At all times it was a distinct pleasure for me to deal with this honest, kindly, and well-meaning gentleman. He undoubtedly deserves the credit for being the university's key man in the manifold relationships that were to be developed between it and Aberdeen.

Sometime in the Fall of 1942 I first became acquainted with John W. Mauchly, who displayed considerable interest in Aberdeen's computing problems. Mauchly in fact had a dual interest in computation. He was both concerned about the technology of computing machines and the usage of them to do statistical weather prediction. His concern with these applications did not mature in the usual way and result in the production of papers on the subject, but it did suffice to keep him thinking about machines to handle the underlying mathematical tasks.

During 1941 Mauchly was so stimulated by his conversations with a man at Iowa State that he was sketching in his laboratory notebook various emendations to the man's ideas. By August 1942 he had advanced in his thinking enough to write a brief memorandum summarizing his ideas; this was circulated among his colleagues and perhaps most importantly to a young graduate student, J. Presper Eckert, Jr., who was undoubtedly the best electronic engineer in the Moore School. He immediately, as was his wont, immersed himself in the meager literature on counting circuits and rapidly became an expert in the field. This was to have inestimable import just a year later.

Mauchly and I had fairly frequent and mutually interesting conversations about computational matters during the Fall of 1942. These talks served to emphasize to me Mauchly's point about the "great gain in the speed of the calculation...if the devices which are used employ electronic means for the performance of the calculation, because the speed of such devices can be made very much higher than that of any mechanical device."

In March 1943 I indicated my very considerable interest in all this to Brainerd, who made available Mauchly's ideas and his own judgment that they were not unreasonable. I then conferred on the problem at some length with Gillon, and we agreed on the desirability of the Ordnance Department underwriting a development program at the Moore School looking toward the ultimate production of an electronic digital computer for the Ballistic Research Laboratory. Gillon in his positive and enthusiastic way pushed the matter forward with great celerity.

There was some concern voiced over the large number of tubes the machine would contain--around 17,000. Some electronic experts expressed apprehensions on this point. The work began on 31 May 1943, and a definitive contract was entered into on 5 June 1943.

To gain some rough measure of the magnitude of the risks, we should realize that the proposed machine turned out to contain over 17,000 tubes of 16 different types operating at a fundamental clock rate or 100,000 pulses per second. This later point means that the machine was a synchronous one, receiving its heart-beat from a clock which issued a signal every 10 microseconds. Thus, once every 10 microseconds an error would occur if a single one of the 17,000 tubes operated incorrectly; this means that in a single second there were 1.7 billion (=1.7 x 10**9) chances of a failure occurring and in a day (=100,000 seconds) about 1.7 x 10**14 chances. Put in other words, the contemplated machine had to operate with a probability of malfunction of about 1 part in 10**14 in order for it to run for 12 hours without error. Man had never made an instrument capable of operating with this degree of fidelity or reliability, and this is why the undertaking was so risky a one and the accomplishment so great. Indeed to this day the computer represents man's most complex device. He has never before or since produced a device where the probability of failure has to be so low, unless it be the space capsules with all their attendant computers. It has been said that, "In addition to its 17,000 vacuum tubes the ENIAC contained about 70,000 resistors, 10,000 capacitors, and 6,000 switches. It was 100 feet long, 10 feet high, and 3 deep. In operation it consumed 140 kilowatts of power."

Above all others the man who made it possible to achieve the almost incredible reliability needed for success was Eckert. He was the chief engineer and had Mauchly as his consultant. Eckert fully understood at the start, as perhaps none of his colleagues did, that the overall success of the project was to depend entirely on a totally new concept of component reliability and on utmost care in setting up criteria for everything from quality of insulation to types of tubes.

Eckert's standards were the highest, his energies almost limitless, his ingenuity remarkable, and his intelligence extraordinary. From start to finish it was he who gave the project its integrity and ensured its success. This is of course not to say that the ENIAC development was a one-man show. It was most clearly not. But it was Eckert's omnipresence that drove everything forward at whatever cost to humans including himself.

It was stated in the ENIAC contract that the university "in cooperation with and under the direction of representatives of the Ballistic Research Laboratory...shall engage in research and experimental work in connection with the development of an electronic numerical integrator and computer...." The university agreed to furnish copies of reports and in the event "the contract results in the fabrication and completion of any part or unit... [it] shall be delivered to the Government...."

At the beginning, at least, Mauchly was to continue to play a key role in the ENIAC project. He alone of the staff of the Moore School knew a lot about the design of the standard electromechanical IBM machines of the period and was able to suggest to the engineers how to handle various design problems by analogy to methods used by IBM. Then as time went on his involvement decreased until it became mainly one of writing up of patent applications. Mauchly was at his absolute best during the early days because his was a quick and restless mind best suited to coping with problems of the moment.

There has been considerable controversy over exactly who invented the ENIAC and the follow-on EDVAC. In the first place, Eckert's contribution, taken over the duration of the project, exceeded all others. As chief engineer he was the mainspring of the entire mechanism. Mauchly's great contributions were the initial ideas together with his large knowledge of how in principle to implement many aspects of them.

Instead of my trying to summarize each person's contributions to what was, at least to me, a joint effort, let me just say that the senior engineers were Arthur Burks and Kite Sharpless, who somehow divided the overall systems responsibility with each other and with Eckert and Mauchly and who designed large pieces of the machine. The others were also important to the project and not one of them could have been easily dispensed with. Their contributions were entirely noteworthy.

Let me now introduce the person who above all others had the greatest influence on the EDVAC, the Moore School's successor to the ENIAC and to all other computers: John von Neumann.

It was his training in formal logics that made him very much aware of and interested in a result which foreshadowed the modern computer. This was the so-called Turing machine. Indeed Alan Turing worked at Princeton under von Neumann's eye on his fundamental paper.

Von Neumann possessed along with all his other accomplishments a truly remarkable ability to do very elaborate calculations in his head at lightning speeds; this was especially noticeable when he would be making rough order of magnitude estimates mentally and would call upon an unbelievable wealth of physical constants he had available.

His great interest in the applications of mathematics was to become increasingly important as time went on, and by 1941 it had become his dominant interest. This was to have the most profound implications for the computer field in particular and for the United States in general. The story used to be told about him in Princeton that while he was indeed a demigod he had made a detailed study of humans and could imitate them perfectly. Actually he had great social presence, a very warm, human personality, and a wonderful sense of humor. These qualities, together with his incredible mental capacity, made him a superb teacher. Eugene Wigner, a lifelong colleague of his, and I wrote of him:

No appraisal of von Neumann's contributions...would be complete without a mention of the guidance and help which he so freely gave to his friends and acquaintances, both contemporary and younger than himself. There are well- known theoretical physicists who believe that they have learned more from von Neumann in personal conversations than from any of their colleagues. They value what they

learned from him in the way of mathematical theorems, but they value even more highly what they learned from him in methods of thinking and ways of mathematical argument.
With real justice it can be said of him, in the words of Landor, that he "warmed both hands before the fire of life."

The contract between the University of Pennsylvania and the Government was typical of research and development contracts of that era. As far as patents were concerned, the contractor had two options available to him; either he could take out the patents and grant the government various royalty- free licenses, or the government would take over the task of patent preparation for him. In either case, "Title to the inventions will remain in the inventors, and an appropriate license to the Government will be execute."

Most universities in this era were quite naive about business matters, and the University of Pennsylvania was no exception. Its officials never bothered to consider how they were going to get their engineers to execute the appropriate licenses, as required under the contract.

The University of Pennsylvania had in those days a vague policy of permitting each employee who requested it all rights to his inventions. This was not an automatic procedure and required a petition by the employee to the Board of Trustees. There was much confusion in the Moore School as to who was entitled to be considered an inventor.

Now the problem of patents on the ENIAC and then a little later on the EDVAC was to have an explosive impact on the University of Pennsylvania. As far back as November 1944 Dean Pender was writing to Dr. George W. McClelland, the then president of the university, asking for a clarification of the university's patent policies. Dr. McClelland responded saying that the Executive Committee had taken no action on the matter. However, after much discussion Eckert and Mauchly wrote President McClelland asking for rights to the inventions made by them in the course of work. McClelland wrote them in March of 1945 granting them this right waiving the university's right to a patent assignment with one stipulation: he provided that they grant the United States Government a nonexclusive, royalty-free license and the university such a license with the further right to sublicense "any established eleemosynary institution to build and to use such devices for essentially noncommercial and nonprofit purposes."

However, a month earlier Eckert and Mauchly had assurances that President McClelland would act favorably on their request. They accordingly had hired an attorney to assist the Ordnance lawyers in preparing the necessary applications. As might be imagined, there was very great heat generated over this entire question of patents. It served to cleave Eckert and Mauchly apart from the university and Moore School officials, and it created tensions between Pender and Brainerd and finally between Eckert and Mauchly on the one hand and Gillon, von Neumann, and me on the other. The reasons for the last rift had to do with publicity and correctness. Gillon and I were very anxious to declassify ENIAC and EDVAC and give them wide publicity throughout the scientific community. We did not however want to hurt Eckert and Mauchly in the process. Thus in November of 1945 Gillon and I were corresponding on this subject. Gillon wrote: "On the protection of Mauchly and Eckert, how much time do they require to file and how will that change our present publicity plans?" Eckert was loath to have any publicity until he and Mauchly had filed their patent applications. Indeed, Eckert "thinks we should say nothing...but simply attend as auditors."

A further exacerbation of the problem had to do with authorships. Both Eckert and Mauchly were much offended that Brainerd had been asked to write an NDRC report, and Mauchly was upset by the fact that Brainerd and Eckert had originally been invited to an MIT conference and he had not. While each of these crises was eventually smoothed over, each served to deepen the rift that was rapidly developing between Eckert and Mauchly on one side and Brainerd and Pender on the other. It should be said in connection with the above-mentioned grievances that Eckert and Mauchly felt with some justice that no one in the Moore School administration had any deep technical understanding of the ENIAC or EDVAC. There was truth in this. The way the dean organized things, Brainerd was so deeply immersed in all the administrative details of the research commitments of the Moore School that he did not have the time or strength to follow in detail the ENIAC or EDVAC projects.

It is my considered opinion that the lack of technical participation by the senior staff of the Moore School was real--probably unavoidable as the school was then structured--and ultimately led to its loss of leadership in the field it had pioneered. It is also my opinion that vigorous technical participation by members of the faculty of the Moore School would have resulted in a further cleavage.

Von Neumann's keen participation and leadership of the logical design work on the EDVAC became a source of substantial conflict between him and me on one side and Eckert and Mauchly on the other. When the discussions leading up to von Neumann's work on the EDVAC had taken place it had been against a background of complete mutual openness and desire to produce the best possible ideas. Later it turned out that Eckert and Mauchly viewed themselves as the inventors or discoverers of all the ideas and concepts underlying the EDVAC. This view was strenuously opposed by von Neumann and me.

Finally, after considerable acrimony a meeting was held 8 April 1947 to try to resolve the problem relating to the EDVAC. This was attended by Dean Pender and several of his associates, Eckert and Mauchly, von Neumann and me, as well as representatives of the legal branch of the Ordnance Department. The upshot of the meeting was that a report by von Neumann called a "First Draft" was treated by the Ordnance lawyers as a publication in the strict legal sense. This meant that the distribution given to that report by me had placed its contents in the public domain, and hence anything disclosed therein became unpatentable. The Ordnance lawyers thereupon withdrew from the task of preparing patents on the EDVAC work in behalf of Eckert and Mauchly. At the meeting von Neumann and I proposed sorting out those ideas which could be attributed to specific people and agreeing to joint patents on the balance. But no agreement could be reached on either procedural or substantive points.

While the placing of the EDVAC report in the public domain was very satisfactory to both von Neumann and me, it ended our close relations with Eckert and Mauchly. There is much correspondence on the whole controversy, but since I was a participant it is probably best if some future historian analyzes the material objectively.

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