The Role of Computer Science during the Manhattan Project

Christina Kohl

June 10, 2015

Contents

1 Introduction

This paper aims at illustrating the close relation between nuclear research at Los Alamos and the development of Computer Science during World War II.

The aid of computers was essential for the success of the Manhattan Project. Considering the goal was to create an atomic bomb, it was impossible to conduct a lot of testing. So most of the research had to be done theoretically. This involved most notably the computation of many complex equations.

This paper first gives a short overview of the mathematical problems, that needed to be solved in order to construct an atomic bomb. Then three different types of computers—Hand Computers, Punched-card Computers, Electronic Computers—and their applications during the Manhattan Project are described in more detail.

2 The mathematical Problems

The main problem was, to compute what will happen during the bomb's explosion, to know exactly how much of which material is needed and how much energy will be released.

"To follow the process from start to finish required modeling the initial propagation of a detonation wave through the high explosive, the transmission of the resulting shock wave through the tamper and into the fissile material (including the reflection of that shock wave as it reached the center), the propagation of another shock wave as the core exploded, the passage of that shock wave (followed by an equally violent rarefaction wave) outward through the remnants of the previous explosion and into the atmosphere, and finally the resulting blast waves reflection if the bomb was at or near the ground." [1]

The different issues that had to be solved during the process can be further divided into the following topics:

- The physical and chemical properties of materials at extremely high temperatures and pressures: equations of state, reaction cross sections, and explosive detonation chemistry.
- Fluid dynamics in its most general sense: the motion of highly deformable materials in the presence of chemical and nuclear energy release.
- Neutron transport: the processes of nuclear fission, the maintenance of a chain reaction, and the prediction of energy release. [2]

These problems involve nonlinear equations, coupling among many variables, and time-varying singularities. These are difficult mathematical problems, that had to be solved numerically.

Gun-type atomic bomb design and critical mass calculations were mostly done with hand-computing, which will be discussed in more detail in section 3. Punched-card machines (section 4) were responsible for implosion and explosion simulations. Nearing the end of the Manhattan Project in 1945, critical hydrogen-bomb equations, which exceeded the capabilities of the punched-card machines, were performed on the first electronic digital computer, the ENIAC. For details view section 5.

3 Hand Computing

At the beginning of the research in Los Alamos in 1943, various models of mechanical calculating machines were ordered. The one which would be used the most, was the Marchant desktop calculator. These machines weighed almost 40 pounds, incorporated 4,000 moving parts, and cycled at 1,300 rpm. [1] The calculators were mainly operated by a group of about 20 'human computers' consisting of the wives of scientists and members of the U.S. Army Special Engineering Detachment (SED).

These devices broke down a lot and needed to be sent back to the factory for repair. Richard P. Feynmann, a graduate Student from Princeton, and Nicholas Metropolos grew

impatient with this process, when more and more calculators were unavailable. They decided to try to repair them themselves. They learned how the machines operated and soon were able to diagnose problems quickly and restore the calculators to service. [3]

4 Punched-Card Computing

In the fall of 1943 Dana Mitchell of Columbia University proposed that IBM punched-card machines should be purchased to speed up long computations. He had already seen their use for the calculation of astronomical tables. [2]

The following set of machines was therefore requisitioned from IBM:

- Three 601 multipliers
- One 402 tabulator
- One reproducer-summary punch
- One verifier
- One keypunch
- One sorter
- One collator [3]

The machines arrived at Los Alamos before the guy who was supposed to help set them up. So Feynmann, Stanley Frankel, a Berkeley graduate student of Oppenheimer's and Eldred Nelson, the group leader of the Theoretical Physics Division, started to unpack and assemble them. They got them to work within two days with the only reference being the wiring blueprints.

The problem of highest priority for the business machines was simulation of implosion, which involved integrating a coupled set of nonlinear differential equations through time. [2] A single punched card represented one point in space and a whole deck of cards represented the state of the implosion at a specific time instant. Each machine computed a limited set of operations on each card. To evaluate a formula the cards had to pass through a sequence of machines. (The result was a new deck of cards that was the starting point for the next cycle.) Integrating one step ahead in the time dimension corresponded to one cycle of a deck of cards through the machines. The cards spent 1 to 5 seconds at each machine and a cycle involved putting each card through about a dozen of them.

An issue with the punched-card machines was, that they contained several hundred relays, which often had dust sticking to them. Therefore to at least one of every three integration steps to contained an error. If this error occurred in one of the more significant digits, part of the integration step cycle had to be run again. [3]

5 Electronic Computing

Through John von Neumann, news about other developments in computing reached Los Alamos. One particularly interesting project was the the first electronic digital computer—the ENIAC—which was being constructed at the University of Pennsylvania.

Originally the ENIAC was supposed to solve ballistic trajectory problems. However von Neumann suggested to use it for the very complex calculations involved in hydrogen bomb design. So Frankel and Metropolis were sent to Pennsylvania to work with the new computer. [3]

The ENIAC employed over 18,000 electron tubes in flip-flop circuits for storing binary digits. It was programmed using cables to interconnect the electron tube registers.

Computations that took days on the punched card machines could be performed in minutes by the ENIAC. [3]

6 Conclusion

If not for the just evolving computers, the construction of the atomic bomb may not have been realizable - or at least not in such a short time.

In addition the Manhattan Project had a large impact on computer science. This goes far beyond World War II. The involved scientists and engineers brought their experience and many new ideas to laboratories, universities, companies and government agencies all over the world.

References

[1] George Dyson. *Turing's Cathedral: The Origins of the Digital Universe (Vintage)*. Vintage Books, 2012.

[2] Francis H Harlow and N Metropolis. Computing & Computers. *Los Alamos Science*, page 133, 1983.

[3] N. Metropolis and E.C. Nelson. Early computing at Los Alamos. *Annals of the History of Computing*, 4(4):348–357, Oct 1982.